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A collage of images representing the wide range of space science research projects pursued in the Space Science Division at Ames Research Center. (Artwork: James Schilling)

Space Science Division

1999 Annual Report

National Aeronautics and Space Administration

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he Space Science Division at NASA's Ames Research Center conducts research programs that are structured around the study of the origins and evolution of stars, planetary systems, and life, and that address some of the most fundamental questions pursued by science, questions that examine the origin of life and our place in the universe, and questions that lie at the heart of the emerging discipline of Astrobiology.

Ames is recognized as a world leader in Astrobiology, defined as the study of life in the universe and the chemical and physical forces and adaptations that influence life's origin, evolution, and destiny. In pursuing this primary Center mission in Astrobiology, scientists in the Space Science Division perform pioneering basic research and technology development to further fundamental knowledge about the origin, evolution, and distribution of life within the context of cosmic processes. To accomplish this objective the Division has assembled a multidisciplinary team of scientists including astronomers, astrophysicists, chemists, microbiologists, physicists, and planetary scientists. It also requires access to the space environment, since many of the critical data needed to elucidate the evolutionary steps outlined above are only available in space in star-forming regions, in the interstellar medium, and in and around planetary environments.

Major elements of the Space Science Division's program include the study of the interstellar gas and dust that form the raw material for stars, planets, and life; the processes of star and planet formation; the evolution of planets and their atmospheres; the origin of life and its early evolution on the Earth; the search for past or present life throughout the solar system with emphasis on Mars; and life support systems for human solar system exploration missions.

Space Science Division personnel participate in a variety of major NASA missions. Division scientists are/were Investigators, Team Members, or Interdisciplinary Scientists on Pioneer, Voyager, Galileo, the Ulysses space physics mission, the Japanese cooled space infrared telescope (IRTS), the Cassini mission to Saturn, and the Kuiper Airborne Observatory. Division scientists are involved in the development of the Stratospheric Observatory for Infrared Astronomy (SOFIA), planetary detection with Kepler, Stardust, the Mars Surveyor program, the Space Infrared Telescope Facility (SIRTF), and Next Generation Space Telescope (NGST).

The programs in the Space Science Division are international in scope, ranging from active participation in international scientific meetings and societies, to collaborative ground-based research projects, to scientific investigations on international flight missions and projects.

Extensive ties are maintained with the academic community through collaborative research programs and development of science curricula materials, and additionally, students at all levels represent a significant component of the Division's on-site research work force.

The Space Science Division represents a unique resource for NASA's Astrobiology Initiative and in support of the Agency's current and future manned and unmanned missions. The science and mission capability of the Space Science Division described here is unmatched by any other NASA Center or national laboratory.

The Division is organizationally divided into four Branches named according to the focus areas of the research conducted by the scientists in those Branches: Astrophysics, Astrobiology Technology, Exobiology, and Planetary Systems (see Figure 1).

In 1999, the Division employed 72 Civil Service personnel, 47 of whom are Ph.D. scientists. This core permanent staff is augmented with approximately 150 scientists and technicians who are non-civil servants resident in Division facilities through mechanisms such as grants, cooperative agreements, support contracts, fellowships, visiting scientist positions, and student internships.

It is common for visiting scientists to spend their summer research or sabbatical time in the Division's laboratories and facilities. Extensive ties are maintained with the academic community through collaborative research programs and also through the development of science curricula materials. The Space Science Division is dedicated to fostering greater interest in careers in the sciences and provides unique opportunities for training the next generation of scientists. Students at all levels – high school, undergraduate, graduate, and post-doctoral – represent a significant component of the Division's on-site research work force. In 1999, 20 National Research Council Postdoctoral Fellows were resident in the Division, 8 undergraduate students were employed through various internship programs, and Division personnel managed the Astrobiology Academy, a competitive program for college undergraduates to participate in hands-on research projects here at Ames Research Center.

In the following section of the Annual Report, the research programs of each Branch are summarized. Within each area, several examples of research topics have been selected (from a total of approximately 130 tasks) for more detailed description. Following that section is a list of publications authored by Division personnel with 1999 publication dates. Finally, if a particular project is of interest, the personnel roster that begins on page 81 may be used to contact individual scientists. \square

Donald L. DeVincenzi

Chief, Space Science Division http://www-space.arc.nasa.gov

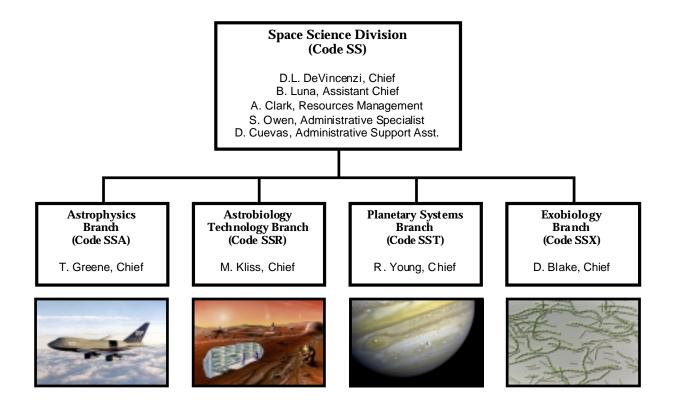


Figure 1: Space Science Division Organization Chart



Astrophysics Branch (SSA) Overview

Scientists in the Astrophysics Branch pursue a wide range of laboratory and observational astronomy research. The Branch is particularly interested in studying the physical and chemical properties of astronomical phenomena by observing their radiation at infrared (and ultraviolet) wavelengths, beyond the range of visible light.

Planets, stars, and the interstellar medium of the Milky Way and other galaxies are rich in infrared spectral features which provide clues to their origins, physics, chemistry, and evolution. SSA researchers use state-of-the-art laboratories, ground-based, airborne, and space-based observatories to conduct their research. Astrophysics Branch scientists, engineers, and technicians also play key roles in developing new NASA space and airborne missions and instruments such as SIRTF, NGST, and SOFIA. The primary products of the Astrophysics Branch are new observations of the universe and new instrumentation developed to make these observations.

Thomas P. Greene

Chief, Astrophysics Branch (SSA)

THE NEARBY STARS (NSTARS) PROJECT

D.E. Backman

NStars is a project based at Ames to produce a comprehensive Web-accessible Database on stars closer than 80 light years to Earth and to promote further observations of those stars by the astronomical community. This effort supports present and future NASA Origins missions such as the Space Infrared Telescope Facility (SIRTF), Stratospheric Observatory for Infrared Astronomy (SOFIA), and the Terrestrial Planet Finder (TPF). For example, TPF is planned as an array of infrared space telescopes capable of detecting Earth-like planets orbiting our nearest neighbor stars. This is such a technically difficult task that TPF will not be able to survey all stars within its distance range during a reasonable mission lifetime. NStars is intended to help select a subset of target stars for TPF that have the best chance of harboring an Earth-like planet.

During FY 1999 a preliminary version of the Database was demonstrated to participants in a special Ames workshop on nearby stars (more below). Capabilities to help users examine data over the Web and define subset lists of interesting stars for further investigation were demonstrated. Substantial comments from the researchers attending the workshop were collected for further improvement of the Database and its user interfaces.

The Nearby Stars workshop was held over 3 days in June '99, organized and hosted by the NStars project scientists. The format involved a small number of invited speakers plus poster presentations. The invited talks addressed major topics in astrophysical research on nearby stars. The invited talks, posters, and notes from discussion sessions will be published as a NASA publication in 2000.

NStars project scientist Dana Backman addressed the SIRTF Science Working Group in March '99 about the NStars Project and its support for definition of SIRTF observing programs. Backman also gave a talk at the SOFIA Star Formation workshop in Santa Cruz in July '99 on possible SOFIA key projects investigating nearby stars.

Five undergraduate students (Avi Mandell, Aaron Burgman, Emma Roberts, Mike Connelley, and Pete Nothstein) worked as research assistants during summer and fall '99 on projects connected to NStars. Their projects included: a) comparison of techniques for determining ages of stars, b) surveys for variability of solar-type stars using a robotic telescope, and c) compilation of archived astronomical data to prepare for SIRTF observing programs. Software, database, and web page development for NStars involved part-time employment of Symtech personnel Sarah West, Eric Vacin, Mick Storm, and Peter Mariani. \square

OBSERVATIONS OF EXTRASOLAR PLANETS

T. Castellano

In the last several years, more than 30 planets have been discovered orbiting other stars. All discoveries to date have been by the radial velocity method whereby extremely small variations in the speed of the star relative to Earth are used to infer the presence of an unseen orbiting companion. More than 20% of the planets discovered orbit their parent stars with periods of less than a week. For these short period orbits, 10% will be oriented such that the planet will periodically pass in front of the star as seen from Earth. An alternate method of detecting extrasolar planets employing high precision measurements of the stars brightness can confirm the existence of the planet and obtain its mass and radius. This technique was convincingly demonstrated when the first ever measurement of the dimming of a star (HD 209458) because of the passage of a orbiting planet occurred in late 1999. This 'extrasolar planetary transit' was discovered independently by two groups and widely reported in the news media.

Soon after the announcement, Ames conducted an archival search of the brightness data of the star HD 209458. The data, collected by the European Hipparcos satellite between 1989 and 1992, revealed a photometric dimming consistent with the observed radial velocity measurements and ground based transit observations. The long baseline in time between the Hipparcos measurements and the present allowed a very precise determination of the planet's orbital period. These results will be published in the Astrophysical Journal Letters. The successful confirmation of an extrasolar planetary transit in the Hipparcos data, suggests that it may be possible to discover more extrasolar planets around sun-like stars using data from the Hipparcos satellite or NASA's planned Full Sky Astrometric Explorer (FAME) satellite.

A novel method for obtaining high precision photometric measurements of bright stars using a spot filter and Charge Coupled Device Detectors on ground-based telescopes has been developed. A demonstration of the technique was performed on the sun-like star HD 187123 in the fall of 1999. No transit of an extrasolar planet was seen, although the required precision was achieved as shown in Figure 2. Additional observations were made of the stars bearing extrasolar planets HD 217107, 51 Pegasi, Upsilon Andromedae and Tau Bootes without result. \Box

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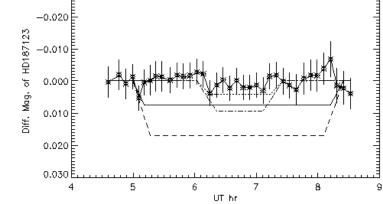


Figure 2: A sample of data for the star HD 187123 compared to a range of simulated possible transit signals produced by Jupiter like planets passing in front of a solar like star.

ORGANIC MATTER IN THE OUTER SOLAR SYSTEM

D.P. Cruikshank, T.L. Roush, Y.J. Pendleton, C. Dalle Ore, T.C. Owen, T.R. Geballe, C. de Bergh, and B.N. Khare

Many solid bodies in the outer Solar System are covered with ices of various compositions, including water, carbon dioxide, methane, nitrogen, and other molecules that are solid at the low temperatures that prevail there. These ices have all been detected by remote sensing observations made with telescopes on Earth, or more recently, spacecraft in orbit (notably Galileo at Jupiter). The data also reveal other solid materials that could be minerals or complex carbon-bearing organic molecules. A study in progress using large ground-based telescopes to acquire infrared spectroscopic data, and laboratory results on the optical properties of complex organic matter, seeks to identify the non-icy materials on several satellites of Saturn, Uranus, and Neptune. The work on the satellites of Saturn is in part preparatory to the Cassini spacecraft investigation of the Saturn system, which will begin in 2004 and extend for four years.

One of Saturn's satellites, Iapetus, exhibits a unique exposure of non-ice surface material that has very low reflectivity, causing the surface to appear entirely black at certain positions in its orbit around the planet. The infrared spectrum of this black surface of Iapetus has been extended into new wavelength regions in the current study, exploring a part of the spectrum that has not heretofore been seen.

In addition to other characteristics of the spectrum of Iapetus, a very strong absorption band at 3 micrometers wavelength is revealed clearly for the first time in the new study. Models of the spectrum using organic solid materials produced in realistic simulations in the laboratory give a strong indication that the black matter on half of Iapetus' surface is indeed organic in nature. The origin and mechanism for emplacement of the black material on the surface of this moon are unknown. The Cassini mission to Saturn will provide data that have a high probability of resolving these issues and further clarifying the apparently unique history of Iapetus.

Other moons of Saturn show similar, though less dramatic, evidence for the presence of macromolecular organic matter mixed with their surface ices, but the chemistry of the organic material appears to be different. The moons of Uranus, Neptune's moon Triton, and the planet Pluto all have black materials on their surfaces that are presumed to be organic in nature. The origins of this material are likely to be different from that on Iapetus, as well, underscoring the extraordinary variety of compositions and histories that the small bodies of the outer Solar System have undergone since their formation. The study in progress at Ames, with colleagues from many other institutions, seeks to explore the nature and origin of organic matter throughout the Solar System, and to explicate any astrobiological connections that emerge. \square

AIRES - THE SOFIA FACILITY SPECTROMETER

E. Erickson, M. Haas, and S. Colgan

An Ames team was selected by peer review to build AIRES, the Airborne Infrared Echelle Spectrometer for SOFIA, the Stratospheric Observatory for Infrared Astronomy. The objective is to develop a facility class spectrometer for use by the international astronomical community. AIRES will be delivered to the Universities Space Research Association (USRA) NASA's prime contractor for SOFIA, who will operate facility instruments for scientists with approved observing programs.

SOFIA is a unique airborne astronomical observatory currently under development. A Boeing 747 will be equipped to carry a 2.7-meter telescope to be operated at altitudes up to 45,000 feet, allowing infrared astronomical observations that are impossible from the Earth. It is being developed jointly by NASA and DLR, the German Aerospace Center, and will be based at Ames with operations beginning in late 2002.

AIRES will operate at far-infrared wavelengths, roughly 30 to 400 times the wavelengths of visible light. This means it will be ideal for spectral imaging of gas-phase phenomena in the interstellar medium (ISM), the vast and varied volume of space between the stars. Measurements of far-infrared spectral lines with AIRES will probe the pressure density, luminosity, excitation, mass distribution, chemical composition, heating and cooling rates, and kinematics in the various gaseous components of the ISM. These lines offer invaluable and often unique diagnostics of conditions in such diverse places as star-forming regions, circumstellar shells, the Galactic Center, starbursts in galaxies, and the nuclei of active galaxies energized by accretion of material on massive black holes. AIRES will provide astronomers with new insights into these and other environments in the ISM. It will also be useful for studies of solar system phenomena such as planetary atmospheres and comets, and a variety of other astronomical problems.

AIRES development began in November 1998. The design incorporates the world's largest monolithic 'echelle' grating (see Figure 3), an optical element which will provide good spectral resolution at far



Figure 3: The ruled echelle grating. Two images of the optical engineer are seen reflected from the facets of the grooves that are at angles of 90 degrees from each other.

infrared wavelengths. Two dimensional infrared detector arrays will be used to simultaneously measure spectra in a number of locations on the sky, and to verify the location on the sky where the instrument is acquiring data. During the past year, a number of significant milestones have been reached, including: a) The optical design has been completed; b) The echelle grating has been fabricated; c) The detector data system has been fabricated and tested with the imaging array detector; d) The baseline project resource requirements have been re-defined and the management revised; and e) An external preliminary design review team, selected by USRA, approved the project for continued development. \Box

CONCEPTUAL STUDY OF NGST SCIENCE INSTRUMENTS

T. Greene and K. Ennico

The Next Generation Space Telescope (NGST) will be the successor of the Hubble Space Telescope and is scheduled for launch in the year 2008. NGST will make unprecedented discoveries in the realms of galaxy formation, cosmology, stellar populations, star formation, and planetary systems. NGST is currently in the conceptual design phase of development, and Ames has been involved in defining and studying the scientific instrumentation it will need to conduct its observations.

Along with scientists at the University of Arizona (Kimberly Ennico, Jill Bechtold, George Rieke, Marcia Rieke, Jim Burge, Roland Sharlot, and Rodger Thompson), and in partnership with Lockheed Martin (Larry Lesyna and the Advanced Technology Center staff), Ames has led and completed a conceptual study of the entire NGST scientific instrument complement. This was one of several international teams selected to study NGST science instruments. The Ames-led team conducted trade studies of specific instrument technologies and implementations, and developed a comprehensive integrated science instrument module (ISIM) concept.

The team found that the science drivers of NGST justify observations from visible (0.4 microns) to far-infrared (35 microns; about 50 times longer than visible to the human eye) wavelengths of light. Imaging capability is required throughout this wavelength range, while spectroscopic capability is required at all wavelengths greater than or equal to 1 micron. Several technologies are key to achieving these capabilities within the cost, schedule, and environmental requirements of the NGST mission. Visible and far-infrared detectors could be developed in time for NGST, and several detector cooling options – including pulse tubes and solid H2 systems – are viable. The team also found that dispersive slit spectrographs are superior to imaging Fourier Transform spectrometers when complete spatial coverage is not required. Dispersive spectroscopy may be best accomplished with conventional slits or micro-shutter arrays instead of micro-mirror arrays due to the large background rejection (greater than a factor of 1000) required at near-to-far infrared wavelengths.

A complement of 7 instrument modules resulted from these scientific and technical considerations by the study team. Two wide-field cameras (each covering about 0.01 square degrees) would be located directly at the focus of the NGST telescope and would image visible to near-infrared wavelengths

(0.4 – 2.5 microns) in a few broad-band filters. A separate visible-light camera would cover a smaller field at the maximum resolution of the NGST telescope. The other four modules would cover near-to-far infrared wavelengths of light (1–34 microns) and would be capable of conducting either imaging or dispersive spectroscopic observations with modest fields and good spatial resolution. The capability of providing both imaging and spectroscopy with relatively simple optical designs is enabled by using transmissive dispersion elements (called 'grisms') for spectroscopy. The conceptual layout of one of these modules is shown in Figure 4.

Several technologies must be developed further in order to implement this design concept and to ensure the success of NGST. Increasing the size (number of picture elements) and reducing the noise of infrared detectors will have the greatest scientific impact at relatively modest cost. Ames is already leading this effort for NGST. Reliable closed-cycle cryogenic coolers must also be developed to cool these detectors to temperatures of 4-30 degrees Kelvin above absolute zero. This task will be eased by the fact that the NGST telescope will always be behind a sun shade and will cool down to approximately 40 degrees Kelvin. However, these and all other NGST systems must be very reliable since NGST will be located approximately a million miles from Earth, far beyond the reach of the Space Shuttle, and will not be serviceable by astronauts. \square

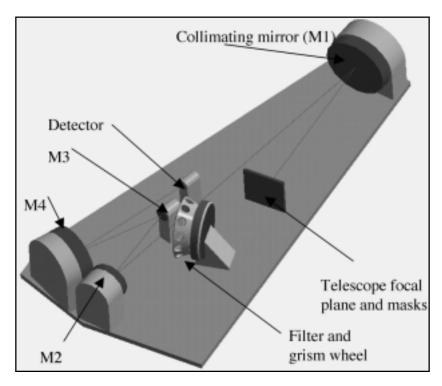


Figure 4: The optical layout of a single instrument module, that can operate as either a camera or spectrograph.

THE SOFIA TELESCOPE ASSEMBLY ALIGNMENT SIMULATOR

M.R. Haas, D.S. Black, J.C. Blair, P.A. Cardinale, N.N. Mai, M.S. Mak, J.A. Marmie, M.J. McIntyre, D.D. Squires, E. Stokely, K. Tsui, and B.C. Yount

NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) is scheduled to begin routine flight operations from Ames in early 2003. To facilitate installation and integration of science instruments with the observatory, a Telescope Assembly Alignment Simulator (TAAS) is being designed and built. Such a facility is required because of the high flight rate, frequent instrument change-outs, and limited access to the telescope cavity.

The TAAS will be an essential part of the Preflight Integration Facility in the SOFIA Science and Mission Operations Center. Before an instrument flies on SOFIA, it will first be mounted on the TAAS to: a) conform all mechanical and electrical interfaces; b) prepare the instrument for flight and assess its operational readiness; c) optically align the instrument with respect to the telescope; and d) measure the weight and moments of the instrument for use in balancing the telescope assembly. Because the TAAS has such a fundamental role in the preparation of science instruments for flight, a second unit will be permanently stationed in the Southern Hemisphere for use during deployments.

Figure 5 shows an advanced design for the main mechanical structure of the TAAS. Science instruments mount on the instrument-mounting flange and their associated electronics are housed in a rack attached to the counterweight plate. In order to provide an accurate mechanical reproduction of the telescope interface, the flange assembly and counterweight plate will be duplicates of those on SOFIA. The bearing unit assembly allows the science equipment to be rotated through the full range of elevation angles appropriate for SOFIA. The drive system powers the rotation and maintains an elevation angle, once selected. Three different infrared light sources have been designed to mount on the rear of the TAAS, for use in instrument alignments. A bore-sight camera assembly will be located in the horizontal tube of the TAAS; it will record focus and bore-sight information and facilitate its transfer to the telescope.

Patch panels will be mounted on the sides of the counterweight rack which are identical to those on the aircraft. Through these panels, the instrument will be connected to all essential services, such as vacuum and gas lines, electrical power, and computer communications to allow a full operational evaluation of the system. The communications will include connection to the observatory's computer simulator for protocol evaluation and testing of critical software interfaces.

The TAAS is mounted on load cells so that it can measure the weight and moments of instrument focal plane packages. These measurements will be used to infer the distribution of counterweights required to balance the SOFIA telescope about all three rotational axes for the given instrument configuration. With this information, the balancing procedure aboard the observatory should take less than an hour.

Preliminary design concepts have been developed for all TAAS subsystems, culminating in a success-

ful preliminary design review in September 1999. Some critical subsystems have been prototyped in the laboratory, including the load cells and a special-purpose controller that modulates the signals

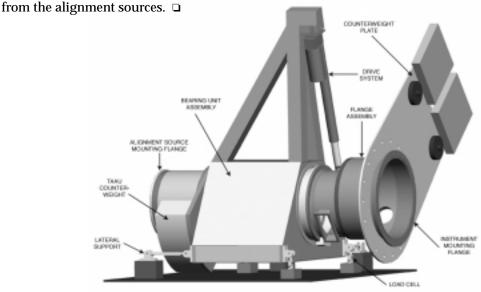


Figure 5: An Advanced Design for the Telescope Assembly Alignment Simulator.

CCD PHOTOMETRY TESTS FOR PLANET DETECTION

D. Koch, W. Borucki, J. Jenkins, L. Webster, and F. Witteborn

For the first time in history, we now know of more planets outside our solar system than in it. All of these extrasolar planets are about the size of Jupiter or larger. We have proposed the *Kepler Mission* to search for hundreds of Earth-size planets. The concept consists of monitoring 100,000 stars continuously for four years for planetary transits. An Earth-size transit of a solar-like star produces a relative change in brightness of $8x10^{-3}$ for a duration of a few to 16 hours depending on the planet's orbit and inclination. We have conducted a technology demonstration to show that a relative precision of better than $2x10^{-5}$ is achievable when all of the realistic noise sources are incorporated in a full-up end-to-end system. A commercially available back-illuminated CCD was used for the tests. The same device can be used in the proposed *Kepler Mission*.

The technology demonstration test facility incorporated the ability to control and measure the following effects on the noise performance of the end-to-end system: varying the CCD operating temperature, changing the focus, varying the photometric aperture, operating over a dynamic range of five stellar magnitudes, working in a crowded star field, reading out the CCD without a shutter, translating the image to several discrete locations on the CCD, operating with a field star five magnitudes brighter than the brightest target stars, operating with spacecraft jitter up to ten times the anticipated amplitude, and simulating the effects of cosmic rays and stellar variability.

The testbed source incorporates all of the characteristics of the real sky that are important to the measurements. It produces the same flux as real 9th to 14th magnitude stars, has the same spectral color as the Sun, has the same star density as the Cygnus region of the Milky Way down to stars as faint as 19th magnitude, has several 4th magnitude stars, and has the ability to produce Earth-size transits for selected stars. The camera simulates all of the functions to be performed by the space-borne photometer, namely, fast optics, a flight-type CCD, readout without a shutter, a high-speed readout of one mega-pixel per second and proto-flight data reduction and analysis software. Piezo-electric transducers are used to provide tip-tilt of the camera to reproduce the motion caused by spacecraft pointing jitter.

To fully demonstrate the concept, transits were created during the testing. Representative transits are shown in Figure 6 for 9^{th} (left), 12^{th} (middle) and 14^{th} (right) magnitude stars. The transit depth is given in equivalent Earth-size and the error bars are the one-sigma noise for the data. \Box

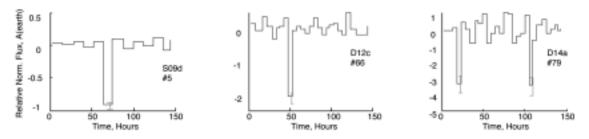


Figure 6: Simulated transits during the running of the long-duration test with all noise sources.

MINIMIZING INFRARED STRAYLIGHT ON SOFIA

A.W. Meyer, S.M. Smith, and C.T. Koerber

The Stratospheric Observatory for Infrared Astronomy (SOFIA) is now being designed and developed, with first light expected in fall, 2002. Flying at 41,000 feet or higher for six hours or more during 120 nights each year, SOFIA will be used for high-resolution observations of celestial objects in the infrared and submillimeter regions, spanning a factor of 1000 in wavelength. In many respects, building SOFIA is a greater challenge than an orbiting observatory would be, but advantages of economy and continuous access make it worthwhile. For work in the infrared, where everything at temperatures above absolute zero can be a source of background interference, the telescope and associated infrared sensors must be carefully designed and constructed to minimize such background. The far-infrared properties of the telescope's surfaces, surrounding cavity walls, and surfaces within focal-plane instruments can be significant contributors to background noise. Infrared radiation from sources well off-axis, such as the Earth, Moon, or aircraft engines may be multiply scattered by dust on the optics, the cavity walls and/or surface facets of a complex telescope structure. This report briefly describes recent efforts at NASA Ames to evaluate some of the infrared properties of the SOFIA telescope surfaces and some of the surface treatments that may be used in focal-plane infrared sensors.

In support of progress in the design and development of the SOFIA telescope, the Non-Specular

Reflectometer (NSR) at NASA Ames was re-activated and upgraded. This enabled the NSR to be use to measure infrared reflectance properties for samples of planned SOFIA telescope system structural materials and associated surface treatments. Measurements of specular reflectance and of Bi-directional Reflectance Distribution Functions (BRDFs) were made at wavelengths from 2.2micr ons to 640micr ons, at two angles of incidence, and at scattering angles as far as 85 degrees from normal. Samples of planned telescope system materials included carbon fiber reinforced plastic (CFRP), insulating foams, and Nomex fabric. Samples of candidate surface treatments for focal-plane instruments included two commercial surface treatments, and several samples prepared at Ames with black paints and other components. The commercial surface treatments investigated were 'Optoblack,' a paint-like surface treatment from Labsphere, Inc. (North Sutton, New Hampshire), and 'Vel-Black,' a carbon fiber applique from Energy Science Laboratories, Inc. (San Diego, California). In general, the samples of telescope structural materials appear to have acceptable far-infrared reflectance and scattering properties, even compared to surface treatments expressly developed to minimize such effects. Figure 7 shows specular reflectance results for the telescope samples, compared to infrared-optimized black paints. The commercial surface treatments appear to have excellent characteristics for use in the far-infrared. Samples prepared at Ames performed well when silicon carbide grit was mixed in. These Ames-prepared samples approached but did not equal the performance of more carefully developed infrared black paints such as Ames 24E2 and Ball Infrared Black (BIRB).

These empirical results can now be incorporated into a software model of the SOFIA telescope, which would provide predictions of likely infrared background noise levels. However, it appears already possible to say from the results of the above work, that the surfaces evaluated will probably not contribute significant infrared stray light. \Box

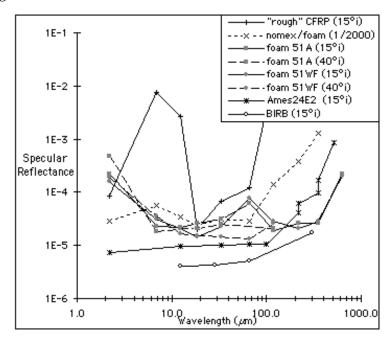


Figure 7: An example of surface treatment samples measured by the NASA Ames Non-Specular Reflectometer. Infrared reflectance spectra for samples of Rohacell white foam, roughened CFRP, Nomex over melamine foam, and for comparison previously published data for the black paints Ames 24E2 and BIRB.

THE SOFIA WATER VAPOR MONITOR

T.L. Roellig, R. Cooper, A. Glukhaya, M. Rennick, and B. Shiroyama

The Stratospheric Observatory for Infrared Astronomy (SOFIA), a 3-meter class telescope mounted in a Boeing 747 aircraft, is being developed for NASA by a consortium consisting of the University Space Research Association, Raytheon E-Systems, and United Airlines. This new facility will be a replacement for the retired Kuiper Airborne Observatory that used to fly out of Moffett Field. As part of this development, NASA Ames Research Center is providing an instrument that will measure the integrated amount of water vapor seen along the telescope line-of-sight. Since the presence of water vapor strongly affects the astronomical infrared signals detected, such a water vapor monitor is critical for proper calibration of the observed emission. The design of the water vapor monitor is now complete and engineering model units (EMUs) have been constructed for all of the important sub-assemblies.

The SOFIA water vapor monitor measures the water vapor content of the atmosphere integrated along the line-of-sight at a 40° -elevation angle by making radiometric measurements of the center and wings of the 183.3 GHz rotational line of water. These measurements are then converted to the integrated water vapor along the telescope line-of-sight. The monitor hardware consists of three physically distinct sub-systems:

- 1) The Radiometer Head Assembly, which contains an antenna that views the sky, a calibrated reference target, a radio-frequency (RF) switch, a mixer, a local oscillator, and an intermediate-frequency (IF) amplifier. All of these components are mounted together and are attached to the inner surface of the aircraft fuselage, so that the antenna can observe the sky through a microwave-transparent window. The radiometer and antenna were ordered from a commercial vendor and were modified at Ames to include an internal reference calibrator. Laboratory tests of this sub-assembly have indicated a signal-to-noise performance over a factor of two better than required.
- 2) The IF Converter Box Assembly, which consist of IF filters, IF power splitters, RF amplifiers, RF power meters, analog amplifiers, A/D converters, and an RS-232 serial interface driver. These electronics are mounted in a cabinet just under the radiometer head and are connected to both the radiometer head and the WVM CPU. Engineering model units for all the important components in this sub-assembly, including the entire RF signal chain, the RF detectors, and the low-noise power supplies have been constructed and tested in the lab. All easily meet their allocated performance requirements.
- 3) A host CPU, that converts the radiometer measurements to measured microns of precipitable water and communicates with the rest of the SOFIA mission and communications control system. A non-flight version of this computer has been procured for development and laboratory testing and the software architecture has been defined. Coding of prototype software has started and communications between the host CPU and the IF Converter Box Assembly have been demonstrated. \square

THE INTERSTELLAR PRODUCTION OF BIOLOGICALLY IMPORTANT ORGANICS

S.A. Sandford, M.P. Bernstein, J. Dworkin, and L.J. Allamandola

One of the primary tasks of the Astrochemistry Laboratory at NASA's Ames Research Center is to use laboratory simulations to study the chemical processes that occur in dense interstellar clouds. Since new stars are formed in these clouds, their materials may be responsible for the delivery of organics to new habitable planets and may play important roles in the origin of life. These clouds are extremely cold (T <50 degrees Kelvin) and most of the volatiles in these clouds are condensed onto dust grains as thin ice mantles. These ices are exposed to cosmic rays and ultraviolet (UV) photons that break chemical bonds and result in the production of complex molecules when the ices are warmed (as they would be when incorporated into a star-forming region). Using cryo-vacuum systems and UV lamps, we simulate the conditions of these clouds and study the resulting chemistry. Some of the areas of progress made in 1999 are described below. Figure 8 shows some of the types of molecules that may be formed in the interstellar medium. Our laboratory simulations have already confirmed that many of these compounds are made under these conditions.

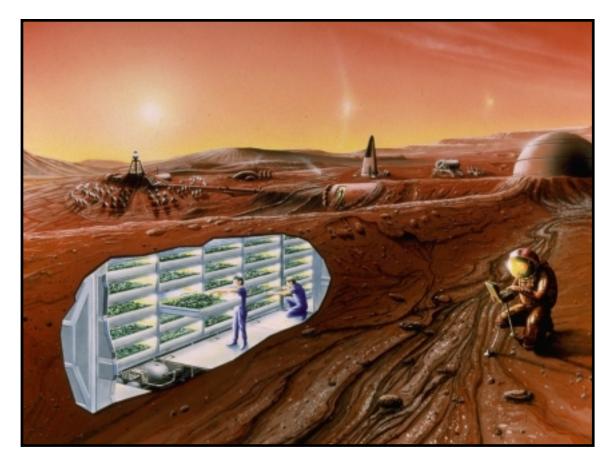
Polycyclic aromatic hydrocarbons (PAHs) are common in carbonaceous chondrites and interplanetary dust particles (IDPs), are abundant in space, and have been detected in interstellar ices. We have shown that PAHs that are UV processed in $\rm H_2O$ ices undergo both oxidation and reduction reactions. The resulting species include aromatic ketones, alcohols, ethers, and $\rm H_n$ -PAHs (partially reduced PAHs). In addition, isotopic studies show that this process can enrich PAHs in deuterium and may explain the D-enrichments seen in aromatics in meteorites. Our most recent studies on the UV processing of the PAH naphthalene in $\rm H_2O$ ice show that various naphthols and 1,4 -naphthaquinone are formed. Since naphthaquinones are common in living systems and perform fundamental roles in biochemistry (they are involved in electron transport), the extraterrestrial delivery of these compounds to the early Earth may be responsible for their presence in biochemistry.

We have continued our studies of the complex organics produced when 10 K interstellar ice analogs are UV irradiated. The residues remaining after the ices are warmed have been analyzed by HPLC and by laser desorption mass spectrometry (in collaboration with Prof. Richard Zare and colleagues at Stanford University). This material contains a rich mixture of compounds with mass spectral profiles resembling those found in IDPs. Surface tension measurements (made in collaboration with Prof. David Deamer of UC Santa Cruz) show that an amphiphilic component is also present. When our residues are dispersed in aqueous media, the organic material self-organizes into 10-40 micron diameter droplets that fluoresce at 300-450 nanometer under UV excitation. These droplets have morphologies that are strikingly similar to those produced by extracts of the Murchison meteorite. The amphiphilic nature of these materials is responsible for the molecular self-assembly and these compounds could have played a role in the formation of early membranous boundary structures required for the first forms of cellular life.

Together, these results suggest a link between organic material photochemically synthesized on the cold grains in dense, interstellar molecular clouds and compounds that may have contributed to the prebiotically important organic inventory of the primitive Earth. \Box

Interstellar Ices (H2O, CH3OH, NH3, CO, CH4, HCN, PAHs, etc.) Urea 2 Naphthol Paraformaledhyde Adenine H_3C 1,4 Naphthaquinone Hexamethylenetetramine H_3C Ribose Lumichrome Polyols Heterocycles (e.g. Bases) (e.g. Aldoses) Menaquinone Alanine Oxidized Aromatics Amines (e.g. Amino Acids) (e.g. Vitamins)

Figure 8: Some of the classes of compounds that may be produced in low temperature interstellar ices by UV photolysis. A number of these species have already been identified or tentatively identified in our interstellar simulations (2-naphthol, 1,4-naphthaquinone, paraformaldehyde, urea, hexamethylenetetramine, and alanine).



Astrobiology Technology Branch (SSR) Overview

The Astrobiology Technology Branch supports fundamental research and the development of advanced technologies in astrobiology as they relate to the exploration of space and understanding life in the universe. Current branch efforts encompass research and technology development for advanced life support, utilization of planetary resources, and astrobiology. Advanced Life Support focused research is directed primarily at physicochemical processes for use in regenerative life support systems required for future human missions and includes atmosphere revitalization, water recovery, waste processing/resource recovery, and systems modeling, analysis and controls associated with integrated subsystems operation. In-Situ Resource Utilization (ISRU) technologies will become increasingly important on every Mars lander between 2003 and a human mission to Mars. The branch focus is on the development of technologies for Mars atmosphere acquisition, buffer gas production, and ${\rm CO_2}$ compression. Research and technology development for astrobiology includes understanding the physical and chemical limits to which life has adapted on Earth, the molecular adaptations that have allowed living systems to inhabit extreme environments, and the application of this knowledge to biotechnology, nanotechnology, and planetary protection. Researchers in the branch also develop flight experiments and associated hardware for shuttle, ISS, and unmanned NASA missions.

Mark H. Kliss

Chief, Astrobiology Technology Branch (SSR)

DYNAMIC MODELING OF LIFE SUPPORT SYSTEMS

C. Finn and H. Jones

Dynamic system models have been developed which track the flow of material through a regenerative life support system over time-periods of months to years. These models are being used to help evaluate system design and operation issues for the Advanced Life Support Systems Integrated Test Bed (ALSSITB). The model captures the main flow stream characteristics associated with atmosphere regeneration, water recovery, crop growth, food processing, and waste processing. The system simulation quantifies the variations in stream flow rates and subsystem processing rates so that estimates can be made on buffer requirements for various system configurations and design options. It is also being used to investigate scheduling, operations, and control issues.

Dynamic modeling is an important tool for developing robust system designs. Static or steady state models are often used to obtain estimates on nominal processor flow rates and re-supply requirements. However, more detailed system design requires information on processor operation ranges and system buffer requirements, which are a function of the system dynamics and control strategy. In general, the level of model complexity needed increases throughout the system design cycle. In the early design phase, simple dynamic models provide useful information for estimating the processing rates and storage sizes needed to meet all of the system performance specifications. More complex models are needed for the design of control systems, the development of failure recovery approaches, and planning how to add redundancy to the system in order to improve system safety and reliability.

A top-level dynamic system model of the ALSSITB has been developed at Ames Research Center to investigate system design issues. The ALSSITB is currently being developed by Johnson Space Center to support long-duration human testing of integrated life support systems. It is comprised of a set of interconnected test chambers with a sealed internal environment capable of supporting a four-person test crew for periods exceeding one year. The life support systems to be tested will consist of both biological and physical/chemical technologies that perform air revitalization, water recovery, biomass production, food processing, and solid waste processing. A variety of system designs for the ALSSITB have been studied to date.

Each system design is described in terms of the set of technologies used, the configuration of the technologies in the system, and the manner in which the system is operated. The overall technology set available for consideration includes technologies that provide various levels of regeneration. For example, life support consumables can either be supplied or produced, and waste products can either be processed, dumped, or stored. An optimal system generally consists of some combination of resupply, *in situ* resource utilization, venting, dumping, and material recycling using physical/chemical or biological processors. System configuration refers to the manner in which the processors are connected for a given set of technologies. For example, there are multiple flow paths possible and various options for the placement and sizing of buffers. System operation strategies need to be investigated, since some system components can be operated in a number of ways. Some technologies can be operated in either batch mode or continuous mode. For batch operation, the batch sizes and

operation schedule can vary. For continuous operation, processing rates can be either constant or variable, and the operational parameters, control objectives and constraints can vary.

Among the ALSSITB designs simulated thus far are systems with different air revitalization systems using various circulation patterns, technology sets and operational strategies. For each system design that was simulated, the results were compared with those of a baseline. This enabled an evaluation of how well each system met performance criteria, by maintaining controlled atmospheres, adequate reserves, etc., and to determine the required capacity for the various processors and storage. \Box

SOLID-STATE COMPRESSORS FOR MARS ISRU

J. Finn, L. Mulloth, and B. Borchers

One important way to extend the science and exploration capabilities of Mars surface missions is to use the readily available Mars atmosphere as a resource to provide critical supplies that would otherwise limit the mission or make it too expensive. Compressed and purified gases, oxygen, important chemicals, and even rover and rocket fuel can be manufactured largely from martian atmospheric gases. This would save the cost of their transport from Earth and ensure that a mission doesn't end when it 'runs out of gas.' These techniques are examples of a popular mission strategy that is generally termed *In Situ* Resource Utilization (ISRU).

The Mars atmosphere consists mostly of carbon dioxide, with relatively small amounts of nitrogen and other gases. At about 0.7 kilo-Pascals (0.1 pounds per square inch) total pressure, the mixed gases are too thin to be useful directly, and so the atmospheric constituents must be separated from each other and compressed. NASA Ames Research Center is developing solid-state adsorption compression and separation technology to acquire the Mars atmospheric constituents and make them available for downstream processing or direct use.

The Ames adsorption compression technology uses a zeolite adsorbent bed that can adsorb large quantities of carbon dioxide at the ambient temperature and pressure of the Mars surface. Its capacity for the other Mars gases is much lower; these gases are drawn through the adsorbent and stored in a second bed for later processing. When the adsorbent is saturated with carbon dioxide, the compressor is isolated and warmed. Carbon dioxide then evolves from the sorbent, resulting in a rapid pressure increase inside the compressor. When the pressure reaches a desired level, the carbon dioxide can be drawn off. The supplied pressure is easily regulated by controlling the power level of the compressor's heater. When the supply of carbon dioxide is exhausted, the bed is allowed to cool and to adsorb another load of carbon dioxide. The cycle can be repeated indefinitely.

The first uses for this adsorption compression technology will be on robotic exploration missions. A prototype for adsorption compression at this mission scale is shown in Figure 9. The one-kilogram device shown has been tested successfully under simulated Mars surface conditions. Under these conditions, it produces approximately 15 grams of carbon dioxide per day at a pressure of 120 kilo-Pascals (17.4 pounds per square inch), and requires an average of seven watts of power during five

hours of production. Larger scale productions will be more economical as the fraction of structural mass decreases; in this case, the anticipated daily production level would be about 250 grams carbon dioxide per kilogram of compressor mass. \Box

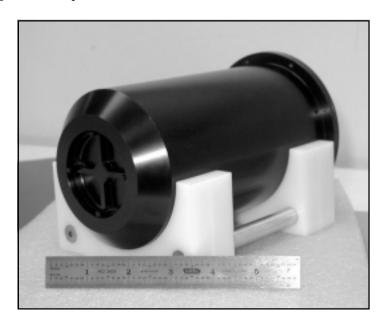


Figure 9: Prototype solid-state adsorption compressor for Mars carbon dioxide, 15 grams/day scale. A nitrogen-argon mixture is produced as a by-product.

ACTIVATED CARBON FROM INEDIBLE BIOMASS

J. Fisher and S. Pisharody

As manned missions become longer, re-supply of life support materials becomes increasingly more difficult and expensive. The expense of re-supply can be avoided by regenerating life support materials. Bioregeneration involves the use of plants to grow food, but plants generate a large amount of inedible biomass, which must be recycled. Incineration is one of the most promising technologies for recycling wastes such as inedible biomass. Unfortunately, inherent to the process of incineration is the formation of undesirable byproducts such as nitric oxide (NO) and sulfur oxides (SO) $_x$. Conventional incineration technologies treat off-gases, such as NO_x and SO_x , by using selective catalytic reduction processes, but these technologies require the injection of expendables such as ammonia to treat the NO_x . Activated carbon can also be used to remove NO_x and SO_x via the process of adsorption.

The Solid Waste Resource Recovery project group is investigating unique ways to use crop wastes to make activated carbon. This would eliminate the need for expendables in the flue gas cleanup during long duration, manned, space missions. It may be possible to make this activated carbon from the inedible biomass available from growing plants in space. Over forty crops are being considered for food production, which will to provide the nutritional needs of crews on long missions. One or more of these plants may be a good raw material for making activated carbon.

The flow diagram (see Figure 10), shows the planned role of the activated carbon as part of the incineration process for resource recovery. The contaminants in the flue gas are adsorbed on activated carbon at room temperature. In a regeneration process at high temperatures, the adsorbed NO_x is reduced by the carbon forming N_2 and CO_2 . The off-gases formed during the activation process are directed back into the incinerator. After several regenerations, the spent carbon is mixed with the incinerator feed and is converted to CO_2 and H_2O in the incinerator. Thus, contaminants are removed without the need for re-supply.

The challenge is to make quality activated carbon. Quality activated carbon is a highly porous, carbon-aceous material. The porous structure is controlled by the nature of the starting material and the process used for carbonization and activation. Conversion of inedible biomass to activated carbon and the use of activated carbon to convert adsorbed NO_x to N_2 gas, has been successfully demonstrated at Ames Research Center. There is an excellent chance that this research will result in a process that will one day be used to manufacture activated carbon in space for use in the life support system. \Box

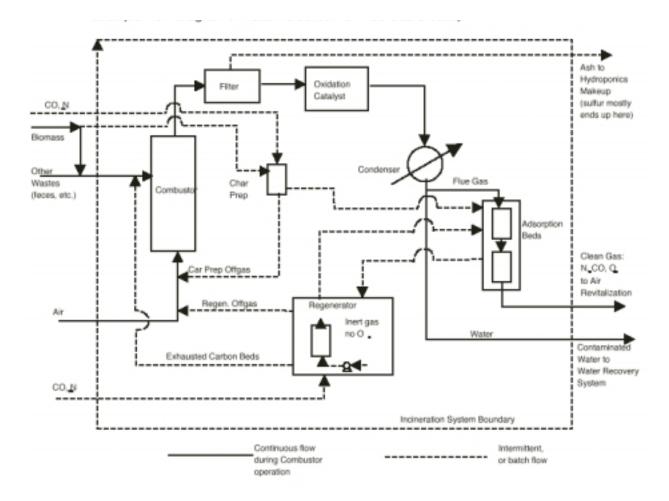


Figure 10: Flow diagram of reactive carbon for flue gas cleanup.

DEVELOPMENT OF THE VAPOR PHASE CATALYTIC AMMONIA REMOVAL PROCESS

M. Flynn and B. Borchers

Ames Research Center has recently completed the development and testing of a prototype Vapor Phase Catalytic Ammonia Removal (VPCAR) system. The VPCAR technology represents the next generation in space flight water recovery systems. Water is the single largest re-supply requirement associated with human space flight, accounting for 87% by mass of an astronaut's daily metabolic requirement. The VPCAR system achieves a mass metric almost an order of magnitude better than the current state of the art water processors. (Mass metric is a technique used to reduce all performance parameters into launch mass.) Incorporating the VPCAR technology into human space flight missions could potentially save hundreds of millions of dollars in re-supply costs, depending on the specific mission scenario. As a result, a human-rated version of the VPCAR technology has been authorized for development, and when completed it will be used for human testing in a closed chamber.

The VPCAR process is a two-step distillation based water processor. The current configuration of the technology is shown in Figure 11. The VPCAR process is characterized by the use of a wiped-film rotating-disk (WFRD) vacuum evaporator to volatilize water, small molecular weight organics, and ammonia. This vapor stream is then oxidized in a vapor phase catalytic reactor to destroy any contaminants. The VPCAR process uses two catalytic beds to oxidize contaminants and decompose any nitrous oxide produced in the first bed. The first catalytic bed oxidizes organics to carbon dioxide and water, and ammonia to nitrous oxide and water. This oxidation reactor contains 1% platinum on alumina pellets and operates at about 523 K. The second catalytic bed reduces the nitrous oxide to nitrogen and oxygen. This reduction catalyst contains 0.5% ruthenium on alumina pellets and operates at about 723 K. The reactor and distillation functions occur in a single modular process step. No scheduled maintenance is required. The system has no re-supply requirements. The process achieves between 97-98% water recovery.

The VPCAR activity is significant in that it represents the development of the next generation of life

support water recovery technology. It also provides an excellent example of how the research and development capabilities of one NASA Center can be integrated into the operational requirements of another NASA Center to reduce the cost of human space flight programs. Ames Research Center's involvement has spanned from the first principle definition to the model development, bench scale and lab scale prototype development, and contract management of the development of a human-rated version of the technology for transfer to a NASA space flight center. Development of the final space flight version will be the responsibility of Johnson Space Center. \square



Figure 11: Vapor Phase Catalytic Ammonia Removal (VPCAR) water recycling system.

SEARCH FOR THE UPPER TEMPERATURE LIMIT OF MULTICELLULAR ORGANISMS NOT SEEN BY TRADITIONAL ENVIRONMENTAL RESEARCHERS ('MONSTERS')

J. Trent

Until fairly recently it was widely believed that the highest temperature to which life on Earth could possibly adapt was around 60°C. Above this temperature, it was assumed, essential biomolecules would be destroyed, and life of any kind would therefore also be destroyed. In the last two decades, however, this assumption has proved to be wrong. Many new species of bacteria and archaea have been discovered in a wide range of habitats that have ambient temperatures well above 60°C. These heat-loving organisms, known as 'thermophiles,' are thriving in thermal hot springs around the world. The hottest of them are living in submarine hot springs that may reach temperatures of 113°C (hydrostatic pressure prevents boiling). The discovery of these hyper-thermophilic microbes has had important scientific and practical consequences. Scientifically, it has expanded our knowledge of the diversity of organisms on Earth, and it has provided important insights into mechanisms for thermostabilization of essential biomolecules. This information is of interest to NASA's Astrobiology program goals of "establishing the limits for life in environments that provide analogues for conditions on other worlds" and "how life evolves on the molecular, organismic, and ecosystem levels."

While many new species of hyperthermophilic bacteria and archaea have been discovered in the last 20 years, few species of thermophilic Eukarya were discovered. Eukarya is one of the three major branches on the tree of life and includes all of the more familiar life forms (Figure 12). For Eukarya the upper temperature limit remains around 60°C, set by some species of fungi found living in self-heating compost piles. Figure 13 shows the current estimates for the temperature range in the universe, the range in which life as we know it exists, and the ranges to which each of the three major divisions of life have adapted. It is not yet clear, however, if the unimpressive upper temperature limits of Eukarya reflects an inability of these organisms to adapt to high temperature habitats or our inability to find Eukarya living in these habitats. Our scientific objective was to answer the fundamental question: what is the upper temperature limits for macroscopic Eukarya on Earth?

To answer this question, researchers at Ames used small, robust, submersible video cameras and lighting system to hunt for macroscopic Eukarya in the hot springs of Yellowstone National Park. The temperatures of these springs ranged in from 31°C to 120°C. It seems likely that there are many undiscovered thermophilic Eukarya lurking in the depths of these hot springs. NASA's video system, like other NASA systems probing distant planets, allows observations in otherwise inaccessible habitats. To date, Eukarya have been observed in springs up to 40°C, but the search goes on at higher temperatures. Ultimately thermophilic Eukarya will be trapped and brought under scrutiny in the laboratory. It seems likely that new species of extremely thermophilic Eukarya will reveal molecular adaptations to high temperatures that have not been observed in the microbial systems currently being investigated. Such adaptations will expand our view of how complex organisms cope with

extreme environments and provide insights into what kinds of organisms may inhabit the hypothetical hydrothermal communities in the subsurface on Mars or the oceans of Europa. For Astrobiology, the search for thermophilic Eukarya will provide guidance for search strategies for life elsewhere in the universe and their discovery here will raise some intriguing possibilities for finding complex life in hydrothermal systems beyond Earth. \square

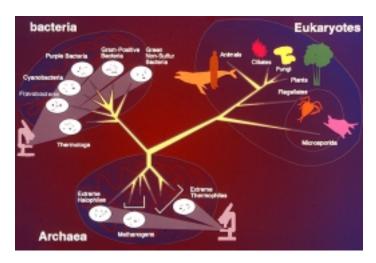


Figure 12: A stylized representation of the three groups that make up the 'tree' of life, indicating the differences in cell types (background), and showing that bacteria and archaea are microscopic single-celled organisms (balloons), while most Eukarya are macroscopic multicellular organisms. NB: bacteria and archaea used to be classified together as 'prokaryotes' based on structural features of their cells, but recent analyses of critical biomolecules indicates that dividing prokaryotes into two separate groups gives a more accurate representation of phylogeny. By both cell structure and molecular criteria, bacteria and archaea are distinct from Eukarya.

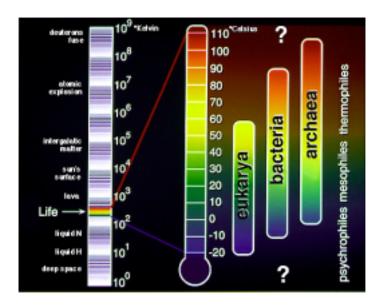
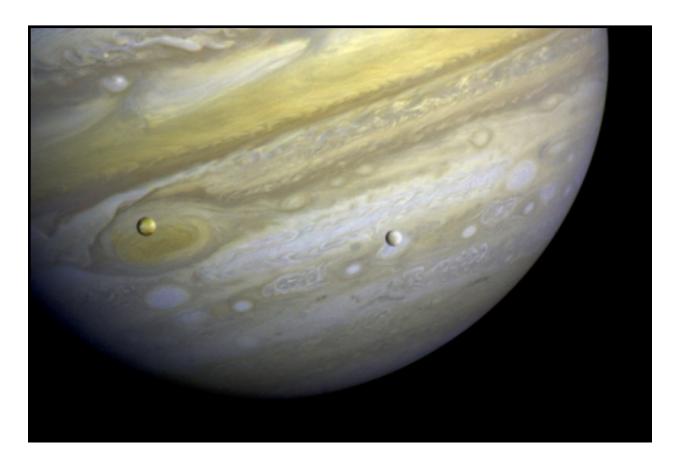


Figure 13: The temperature range in the universe (°K), the temperature range for life and for the three major divisions of life (°C) – Eukarya, bacteria, and archaea. The characterization of organisms based on temperature ranges for optimum growth (psychrophiles <15°C; mesophiles 15-50 °C; and thermophiles >50°C) are indicated to the right. The question marks indicate that we do not yet know the upper temperature limits for any the three divisions of life.



Planetary Systems Branch (SST) Overview

Principal research programs in the Planetary Systems Branch include studies of the formation of stars and planets and the early history of the solar system, studies of planetary atmospheres and climate, investigation of the dynamics of planetary rings and magnetospheres, work on problems associated with the Martian surface including resource utilization and environments for the origin of life, and other programs (chiefly theoretical) involving galaxy dynamics, radiative processes in stars and the interstellar medium, and investigation of the physical and chemical conditions in molecular clouds and star formation regions. Scientists in the branch also support NASA flight missions through participation on various mission science teams. The primary product of the Branch is new knowledge about the nature of the universe, presented and published in the open literature.

Richard E. Young

Chief, Planetary Systems Branch (SST)

ILLUMINATION OF YOUNG STELLAR DISKS

K.R. Bell

The planets in our solar system formed from a gaseous disk known as the solar nebula. Disk-shaped nebulae thought to be analogous to the solar nebula are now commonly observed around solar mass stars younger than a few million years in nearby regions such as the Taurus-Auriga molecular cloud and the Orion Nebula. Images of these disks are obtained with facilities such as the Hubble Space Telescope; spectra are obtained with the Infrared Astronomical Observatory and various ground-based observatories such as the Keck Telescope on Mauna Kea. Studying these systems provides insight into the development of our own planetary system as well as clues about the likelihood of the evolution of similar life-bearing systems around other stars.

The collapse of a molecular cloud core leads the to formation of a protostellar system composed of a star and circumstellar disk. Probably ten to fifty percent of the final mass of the star is accreted in the initial collapse, which occurs on a time-scale of several tens of thousands of years. Gravitationally induced spiral arms rapidly transport much of the remaining nebular mass inward to the central protostellar core. After perhaps a hundred thousand years, the system will consist of a central protostar, which is slowly contracting and radiating its excess gravitational energy. It will be surrounded by a disk of remnant material with a mass no greater than one quarter of the mass of the central star. This gaseous disk persists for several million years during which it is slowly depleted by accretion onto the central object, dispersal by stellar wind and radiation, and the formation of planets.

Infrared radiation from these systems can be analyzed to determine the temperature profile of the disk's surface. There are three major heat sources in these disks: heating due to the local release of gravitational energy by material slowly spiraling inward toward the central star, heating due to the capture and re-emission of stellar radiation, and heating due to the capture and re-emission of radiation from facing disk surfaces. The latter two components depend sensitively on the shape of the disk. Models which treat each disk annulus as a plane-parallel atmosphere suggest that the distance between midplane and photosphere of the disk at any given radius is largely determined by the opacity of material at the high density midplane. A schematic profile of a low-mass flux disk is shown in Figure 14. The reprocessing of radiation within the system is indicated by arrows.

In the inner regions, the disk is hot enough for dust to be destroyed at the midplane, and the disk thickness increases strongly with radius. In this region, the disk's surface is strongly heated by radiation both from the luminous protostar and from facing disk surfaces. At larger radii, where the disk is cooler, dust, which provides an additional source of opacity, is condensed throughout the disk's atmosphere. In this region, the disk's thickness increases more slowly, and stellar radiation cannot illuminate the surface. The transition between the two regimes occurs at roughly the present day orbit of the Earth and suggests that the outer planets formed under cooler conditions than would be expected if the disk were assumed to flare uniformly with radius. \Box

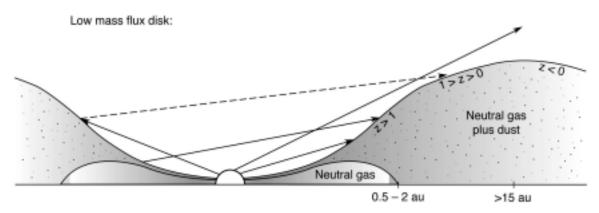


Figure 14: A schematic profile of a low mass flux disk around a solar mass star. The trend of the disk's thickness with radius, H(r), is controlled by the local opacity. Note that H(r) is proportional to r^{Z} . In the inner regions, the star illuminates the disk's surface; at larger radii, the disk is in shadow.

DETECTION OF AN EXTRASOLAR PLANET

W.J. Borucki, D. Caldwell, D.G. Koch, L.D. Webster, J.M. Jenkins, Z. Ninkov, and R. Showen

The objective of this research is to determine the occurrence frequency and the properties of extrasolar planets.

Information on the number, size, mass, spacing, and composition of the planets in other planetary systems is needed to refine our models of planetary system formation and the processes that gave rise to their present configurations. The recent discoveries provide tantalizing glimpses of the large variety of planetary systems that exist and make it possible to begin an investigation of the role of the giant planets. To obtain information on the statistical properties of the giant inner planets, and to develop the statistical inter-dependencies of these properties, it is necessary to observe a variety of stellar spectral types and stellar compositions over a range of semi-major axes.

A small CCD photometer dedicated to the detection of extrasolar planets has been developed at Ames and put into operation at Mt. Hamilton, California. It simultaneously monitors 6000 stars brighter than 13th magnitude in its 49 square-degree field of view. Observations are conducted all night every clear night of the year. A single field is monitored at a cadence of eight images per hour, for a period of about three months. When the data are folded, in order to discover low-amplitude transits, transit amplitudes of 1% are readily detected. This precision is sufficient to find jovian-size planets orbiting solar-like stars, which have signal amplitudes from 1% to 2%, depending on the inflation of the planet's atmosphere and the size of the star.

Recent observations made with the Vulcan photometer produced over one hundred variable stars, many not previously known. About fifty of these stars are eclipsing binary stars, several with transit amplitudes of only a few percent. Three stars that showed only primary transits were examined with high-precision spectroscopy. Two were found to be nearly identical stars in binary pairs orbiting at double the photometric period and the third was found to be a high mass-ratio single-lined binary star.

The November 22, 1999 transit of a planet orbiting HD209458 was observed and the predicted amplitude and immersion times were confirmed. These observations show that the photometer and the data reduction and analysis algorithms now have the necessary precision to find companions with the expected area ratio for jovian-size planets orbiting solar-like stars.

In early November of 1999, two groups announced the discovery of a planet orbiting HD209458 in the Pegasus constellation. The symbols shown in Figure 15 shows the extinction-corrected, normalized light curve we obtained for HD209458 on November 22, 1999. Because this event was the last opportunity to observe the transit, observations were made, even though the star was setting during the transit. Consequently, only the first portion of the transit is seen. The solid line represents the predictions based on the work of Charbonneau et al. and Castellano et al. 1999. Both the limb-crossing time (25 minutes) and the measured amplitude of the transit (1.6%) are in excellent agreement.

Ordinarily, photometry is done as close to the meridian as possible to mitigate the error introduced by scintillation and rapid extinction variations that are associated with high air mass. For this reason, measurements are usually made at air-mass less than 1.5 and seldomly made at an air mass as large as 2.0. However to obtain the data on November 22^{nd} , the measurements were made as the air mass ranged from 1.5 to 4. Figure 16 shows the measured rapid increase in standard deviation (SD) of the fluxes of the seven comparison stars at the time of the measurements. The solid curve shows the expected level of scintillation noise. The agreement between these measurements and the predictions of the scintillation noise demonstrates that the system was operating at a precision limited only by properties of the atmosphere. The observations were terminated at an air mass of four because the signal to noise ratio had dropped below 2.5 at that point. \Box

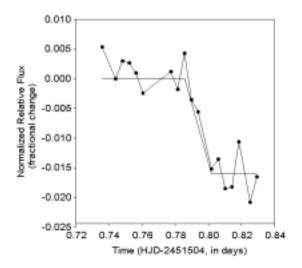


Figure 15: Comparison of the Measured and Predicted Flux for the November 22, 1999 Transit of a Planet Orbiting HD209458.

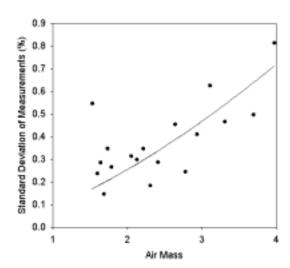


Figure 16: Comparison of the standard deviation of the fluxes of the comparison stars with the prediction of scintillation noise by Young (1974).

COMPOSITION OF DUST ALONG THE LINE OF SIGHT TOWARD THE GALACTIC CENTER

J. Chiar, A. Tielens, and D. Whittet

The composition of dust and ice along the line of sight to the Galactic Center (GC) has been investigated through analysis of mid-infrared spectra (2-13 micron) from the Short Wavelength Spectrometer on the Infrared Space Observatory (ISO). The path to the Galactic Center samples both diffuse interstellar matter and dense molecular cloud environments, by performing a phenomenological comparison with well-studied sightlines known the sample these distinct environments. We have been able to separate spectral absorption features arising in these components towards the Galactic Center. Dust absorption features along the lines of sight toward Sagittarius A* (Sgr A*) and the Quintuplet sources (GCS3 and GCS4) are the primary targets in this endeavor. Molecular cloud material is unevenly distributed across the Galactic Center. Measurements of absorption features due to abundant solid state species, such as water-ice and carbon dioxide, reveal that there is more molecular cloud material along the line of sight toward Sgr A* than the Quintuplet sources. The Sgr A* sight-line has a rich solid state infrared spectrum which also reveals strong evidence for the presence of solid methane, ammonia and formic acid in the molecular cloud ices.

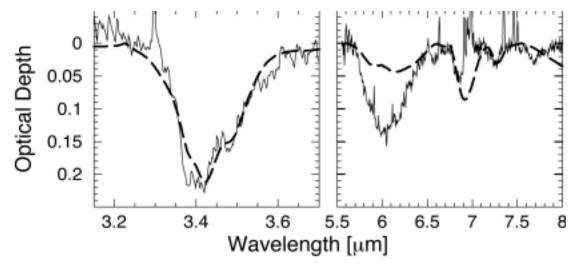


Figure 17: Mid-infrared spectrum of Sagittarius A* (solid line) compared with a laboratory HAC analog from Furton (Rhode Island College) (dashed line). The HAC spectrum is well representative of the interstellar absorption features at 3.4, 6.8 and 7.3 microns.

Hydrocarbon dust in the diffuse interstellar medium along the line of sight to the GC is characterized by absorption features centered at 3.4, 6.8, and 7.3 micron. Ground-based studies have identified the 3.4-micron feature with the C-H stretch vibration mode of aliphatic (chain-like) hydrocarbons. Prevailing theories regarding the production of this robust organic interstellar grain component assume energetic processing of simple interstellar ices (water, carbon monoxide, methane, and ammonia) present in dense molecular clouds. ISO observations have provided the first meaningful observations of the corresponding modes of these hydrocarbons at longer wavelengths, enabling us to rule out

some laboratory analogs and therefore the production routes of these organics. The integrated strengths of the three observed absorption features suggest that some form of hydrogenated amorphous carbon (HAC), rather than processed ices, may be their carrier. Figure 17 shows an impressive match to the observed absorption features with a HAC produced in the laboratory by Douglas Furton (Rhode Island College). We have attributed an absorption feature that is centered at 3.28-microns in the GCS3 spectrum to the C-H stretch of aromatic (ring-like) hydrocarbons. Since this was the only feature detected, and the C-C stretch counterpart (at 6.2 micron), toward the Quintuplet region, but not toward Sgr A*, one of the key questions which now arises is whether aromatic hydrocarbons are a widespread component of the general diffuse interstellar medium, analogous to aliphatic hydrocarbons. \Box

PLANETARY RINGS

J.N. Cuzzi, J. Lissauer, I. Mosqueira, M. Showalter

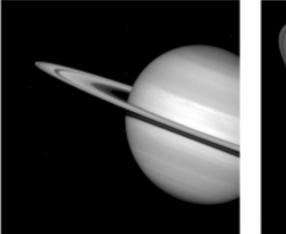
In addition to the natural curiosity inspired by their unusual appearances, planetary rings present a unique dynamical laboratory for understanding the properties of collisional particle disks which might help us understand the accretion of the planets. Ames maintains the Planetary Data System's Rings Node (http://ringmaster.arc.nasa.gov/), which archives and distributes ring data from NASA's spacecraft missions and from Earth-based observatories. We now have on line the entire archive of images from the Voyager missions to the giant planets, with catalogs to help users find the images they need. We have available all the images of Saturn obtained by the Hubble Space Telescope during 1995, when the rings were seen edge-on to the Earth.

An important theoretical advance occurred in the development of a new theory for how narrow, elliptical rings, with nested elliptical orbits, preserve their shape over long periods of time in the face of the tendency of their inner orbits to precess more rapidly than their outer orbits, causing misalignment and collisional disruption. The major previous theory relied exclusively on ring self-gravity to provide the slight counteracting force needed to prevent this, but the mass implied was much smaller than that believed to lie in these rings based on other observations. This year, new physics was added to the equations of motion in the form of pressure tensors in dense particle layers that behave like traffic jams. The new physics turns out to make it more difficult for self-gravity to maintain the alignment of the nested orbits, and boosts the needed mass density into much better agreement with observations.

New observational results were also obtained from analysis of extensive Hubble Space Telescope (HST) observations of Saturn's rings, taken over the last three years as the ring opening angle increased as seen from Earth and Sun (Figure 18). These new observations, taken in eight different colors (several not observable from the Earth) show for the first time that the ring brightness varies with phase angle but not with ring opening angle. This makes it clear that the reflectivity is caused by multiple scattering within a granular regolith on large ring particles, but not between ring particles. This led to the realization that the ring particles are less red than previously determined from Voyager observations at a higher phase angle. Furthermore, the HST data provide evidence for increased

absorption by water ice in certain parts of the rings relative to others, indicating differences in either the surface coverage of surface grain size on the particles. Also, the optically thinner parts of the rings, where the particles have been known to be darker (its inner or C ring, and the Cassini division lying between the main A and B rings), reveal an unassigned absorption feature in the 850-nanometer spectral range. Tentative evidence for such absorption had been hinted at in earlier observations, but the new observations not only verify its existence, but clearly show that the absorber is localized to the C ring and the Cassini Division. We obtained a high-resolution HST image of Saturn's faint G ring that shows that the radial distribution of large particles is similar to that of tiny dust grains observed by Voyager and Galileo. The HST data are being used now in planning Cassini observations of Saturn that will begin in 2004.

Finally, new analyses of Voyager data show that the bright knots and clumps in the curious F ring of Saturn are transient. A few are seen to appear and then dissipate in a matter of days; these are probably caused by puffs of debris from impacts of meteoroids into the larger ring bodies. However, most clumps persist for a matter of months and are probably caused by the more gentle collisions among the bodies themselves. In addition, smaller ring clumps are periodic and show the characteristic spacing one would expect from gravitational interactions with the nearby 'shepherding' moon, Prometheus. Our dynamical models suggest that this periodic tug between the ring and moons may also give rise to a random component in Prometheus' orbit, as has been observed in recent HST images. \square



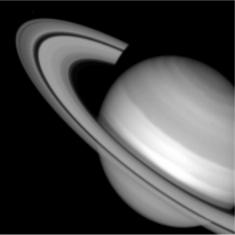


Figure 18: Typical HST images of Saturn's rings at two different opening angles. The spatial resolution is adequate to easily resolve color and compositional differences between many different regions of the rings.

PRIMARY ACCRETION IN THE PROTOPLANETARY NEBULA

J.N. Cuzzi, R.C. Hogan, S. J. Desch, J.M. Paque, and A.R. Dobrovolskis

'Primitive' objects in the meteorite record represent the first large bodies to accumulate in the protoplanetary nebula – a vast data set that has had little context for interpretation. The accretion of primitive bodies almost certainly occurred in the presence of gas. Ames' efforts focus on numerical modeling of particle-gas interactions in turbulent flows, and understanding meteorite properties in the light of theoretical models.

A dense layer of particles orbiting in the midplane of a protoplanetary nebula at close to the unperturbed (or Keplerian) orbital rate, generates a vertical velocity shear and associated turbulence, which prevents the particles from settling completely to the midplane and becoming gravitationally unstable (i.e. from collapsing into planetesimals). However, it was thought possible that damping of the turbulence by the particles themselves might allow the particles to settle into an unstable layer. This year, a study was completed which modeled the evolution of such a layer that incorporated a new model for the damping effects of the particles on their self-generated turbulence. While turbulence damping does flatten the layer, previously neglected terms were uncovered during the study that disperse the layer even more effectively, with the end result that the layer is even less flattened (more stable) than previously believed.

In prior years, Ames developed a hypothesis to explain the prevalence of millimeter-sized 'chondrules' in chondritic meteorites by the mechanism of preferential concentration of aerodynamically selected particles in three-dimensional turbulence. The theory makes specific predictions as to the relative abundance distribution of the concentrated particles. To test the theory, we disaggregated four primitive chondritic meteorites and measured the relative distribution of particles as a function of the product of their radius and density (the important determinants of the particle's aerodynamic stopping time). Comparisons of the theoretical predictions (open symbols) and meteorite data (filled symbols) are shown in Figure 19 for these four meteorites. Relative abundances are plotted as functions of the Stokes number (St), or ratio of particle stopping time to Kolmogorov eddy time. It has been realized for several years that the concentration is maximized for particles with St =1, but not that the distribution function was so narrow. We also completed a multi-fractal theory to predict the magnitude of turbulent concentration at much higher Reynolds numbers than achievable numerically. The concentration is so large that mass loading (the feedback effect of the particle phase on the gas turbulence itself) must be considered before further modeling efforts can proceed. This theory might be of interest to terrestrial cloud modelers as well.

The prevalence of chondrules in meteorites (up to 80% in some classes), implies that they were pervasive in the nebula. Mineralogical studies imply that the favored melting process occurred on short time-scales, over limited spatial scales, and in a relatively cool environment. Lightning, often observed in dry turbulent environments on the Earth, has been studied before and rejected by others. We combined two new insights: the ability of 'triboelectric charging' due to collisions between

chemically dissimilar grains (large silicate chondrules and fine metal grains) to produce large positive charges on the silicate chondrules, and the ability of turbulent concentration to concentrate the charged chondrules and build up sufficient voltage to initiate large lightning strokes. Nebula lightning might also have implications for protoplanetary nebula chemistry. \Box

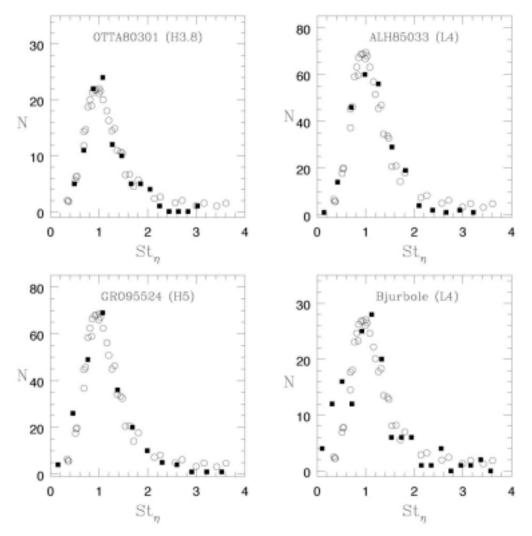


Figure 19: Predicted (open symbols) and observed (filled symbols) distributions of particle size-density product as functions of their aerodynamic stopping time, as normalized to the Stokes number St (subscripted here by the Kolmogorov scale) by dividing by the Kolmogorov eddy turnover time. The observed data are from four different primitive meteorite samples. The agreement is quite good. We also found (not shown here) that using the actual density of each object rather than the average density of all objects noticeably improves the fit, as expected if aerodynamic sorting had operated to determine the chondrule size distribution.

THE CALCULATION OF MOLECULAR OPACITIES

R. Freedman

The theoretical modeling of the properties and emergent spectra of extra solar giant planets and brown dwarfs requires an accurate and detailed knowledge of the sources of molecular opacity in these objects. In the past few years, many new extra solar planets and brown dwarfs have been discovered using new observational techniques and better, and larger telescopes. To better understand the physical properties of these new objects and to relate their properties to the properties of other solar systems, astronomers have been using computer-generated models to reproduce their observed properties. This allows a direct comparison between theory and observations and helps to constrain physical properties such as mass, radius and chemical composition. These objects span the range between the gas giants of our own solar system (Jupiter), and objects almost large enough to burn hydrogen in their interior and thus become stars (brown dwarfs). An accurate theoretical model requires a thorough knowledge of the molecular opacities of a large number of different species, since the temperature in the atmospheres of these objects spans a range from 100 degrees Kelvin up to several thousand. Because of the wide range of physical conditions encountered, modelers need molecular opacities up to a range of temperatures that go far beyond the normal range of molecular data from laboratory studies. The purpose of this research is to extend the range of available molecular opacities up to the higher temperatures needed by the modelers.

This has been accomplished by using a combination of theoretical techniques combined with available observational data to predict lines of various molecules such as $\mathrm{CH_4}$, VO, and CrH . As an example of what has been accomplished, consider the cases of $\mathrm{CH_4}$, $\mathrm{H_2O}$, and TiO : (methane, water, and titanium oxide). The list of spectral lines was extended for all these species to include lines that will become important at higher temperatures, even though these lines are practically unobservable at room temperatures. Water and methane, in particular, are very important sources of opacity in these objects and the inclusion of adequate opacity is very important in a proper evaluation of their spectra and in constructing physically realistic models. In doing this work, the researcher made use of the work of other Ames researchers especially the work of Dr. David Schwenke of the Computational Chemistry Branch. Comparison with observations shows that more work remains to be done to provide opacities that are physically realistic at the highest temperatures. This is especially true for methane and less so for water. Even so, the latest models for objects such as the brown dwarf Gl229B (Gliese 229B) show good agreement with the best available observations. \square

THE CENTER FOR STAR FORMATION STUDIES

D. Hollenbach, K.R. Bell, P. Cassen, and G. Laughlin

The Center for Star Formation Studies is a consortium of scientists from the Space Science Division at Ames and the Astronomy Departments of the University of California at Berkeley and Santa Cruz. This consortium, under the directorship of D. Hollenbach, conducts a coordinated program of theoretical research on star and planet formation and supports postdoctoral fellows, senior visitors, and students.

Consortium members meet regularly at Ames to exchange ideas and present informal seminars on current research. Each Summer, a week-long workshop on selected aspects of star and planet formation is convened.

In July 1999 the Ames members of the Center together with members of the Stratospheric Observatory for Infrared Astronomy (SOFIA) team held an international workshop entitled "SOFIA and Star Formation." The week-long workshop, held on the University of California at Santa Cruz campus, had approximately 175 attendees. Ames scientists E. Erickson and D. Hollenbach were invited to speak and an afternoon discussion on "Key Star Formation Projects for SOFIA" led by L. Caroff (Ames). One purpose of this workshop was to bring theoretical and observational astronomers together with the instrumentalists working on SOFIA instruments in order to stimulate new ideas for SOFIA observational projects related to star formation.

One focus of the 1999 Ames portion of the research work of the Center, involved the effect of ultraviolet radiation from young massive stars on the star-forming clouds of gas and dust that typically surround them or lie close to them. These clouds, called "Giant Molecular Clouds" or GMCs, typically contain 100,000 solar masses of gas and dust and are the dominant sites of star formation in galaxies. The GMCs consist primarily of cold molecular hydrogen gas found in a very 'clumpy' structure bound together by gravity. Thousands of stars are formed in each cloud before it is dispersed in roughly ten million years by the ultraviolet radiation from the most massive stars formed in the GMC. The ultraviolet radiation photoevaporates the clumps in a GMC, destroys the molecules, and heats the gas until the thermal pressure creates a catastrophic expansion of the GMC. These processes disperse the cloud and terminate the star formation process, thereby helping to explain why GMCs do not convert higher fractions of their mass into stars before evaporating into the diffuse interstellar medium. The heating of the gas leads to the emission of characteristic infrared spectra that can be analyzed to determine the physical and dynamical properties of the evolving clouds.

Another focus of the Ames portion of the Center research in 1999 involved the formation and propagation of spiral density waves in the orbiting disks of gas and dust that circle a newly formed star and which ultimately form planets. These spiral density waves affect the evolution of the density and angular momentum in these disks, and therefore the planet-forming characteristics of the disks. Through a combination of analytic analysis and numerical simulations, it was shown that two competing hypotheses explaining the cause of spiral structure in self-gravitating disks, had an underlying unity. This provided a much better understanding of how mass and angular momentum are transported through protostellar disks. This work could also be generalized to the self-gravitating disks, which characterize galaxies, and thereby cleared up a long-standing debate in the galactic structure community.

The theoretical models of the Center have been used to interpret observational data from NASA facilities such as the Infrared Telescope Facility (IRTF), the Infrared Astronomical Observatory (IRAS), the Hubble Space Telescope (HST), and the Infrared Space Observatory (ISO, a European space telescope with NASA collaboration), as well as from numerous ground-based radio and optical telescopes. In addition, they have been used to determine requirements on future missions such as the Stratospheric Observatory for Infrared Astronomy (SOFIA) and the proposed Space Infrared Telescope Facility (SIRTF). \Box

MARS ATMOSPHERE AND CLIMATE

J.L. Hollingsworth, R.M. Haberle, and J. Schaeffer

Furthering our understanding of the global atmospheric circulation on Mars is the focus of this research at NASA Ames. As in Earth's atmosphere, Mars' atmospheric circulation exhibits variability over a vast range of spatial and temporal scales. Some of these processes are driven by similar physical processes (e.g., Hadley circulation cells; global-scale thermal tidal modes; planetary waves forced via flow over large-scale orographic complexes like Earth's Himalayan plateau; and developing, traveling and decaying extra-tropical weather cyclones associated with pole-to-equator thermal contrasts). Other sources of variability arise from distinctly martian physical mechanisms (e.g., condensation (sublimation) during the winter (summer) season of the atmosphere's primary chemical constituent (predominantly CO_2), and regional- and global-scale dust storms). Ultimately, these investigations aspire to improve our knowledge of the dynamics of the planet's present environment and past climates, and from a comparative planetology perspective, to better understand similar processes that govern the dynamics of the Earth's climate.

In this endeavor, the primary tool used is the Ames Mars General Circulation Model (MGCM). The MGCM is a time-dependent, three-dimensional, numerical model of the atmosphere's hydrodynamic state as determined by self-consistent algorithms for radiative (e.g., solar and infrared absorption, emission and scattering in the planet's tenuous and frequently dust-laden atmosphere) and near-surface processes (e.g., a boundary-layer dissipation associated with atmospheric turbulence). In parallel efforts, spacecraft data from the recent Mars Pathfinder mission and the on-going Mars Global Surveyor (MGS) mission are utilized to validate the climate-simulation results, while at the same time, both mechanistic and full-up MGCM simulations can offer a global context for the remotely sensed data.

Investigation of the middle and high latitude meteorological environment using a very high-resolution version of the MGCM has recently been conducted. This research is motivated by Hubble Space Telescope (HST) observations of 'comma'-shaped cloud formations and large-scale dust activity in the polar region during early northern spring and summer, and, by MGS Mars Orbiter Camera (MOC) imaging of condensate cloud structures in the polar environment during this season. Modeling at high spatial resolution is necessary in order to illuminate processes important to local and regional dust activity, as well as condensate cloud formation, structure, and evolution within the edge of Mars' seasonal polar caps. It has been found that near-surface and upper-level fronts (i.e., narrow zones with enhanced mass density, momentum and thermal contrasts within individual extra-tropical cyclones) can form in Mars' intense high-latitude baroclinic zone, and the associated frontal circulations are sufficient to raise dust in high latitudes.

Shown in Figure 20 in a spherical projection view, are examples of these results for simulations that include recent MGS Mars Orbiter Laser Altimeter (MOLA) topography in the climate model. Solid contours correspond to potential temperature and arrows correspond to the instantaneous horizontal wind. Near the prime meridian (i.e., the center longitude of each panel), a clear rarefaction, stretching,

and deformation of the temperature field can be seen. This rarefaction is caused by intense local circulations associated with traveling weather systems in middle latitudes (i.e., transient baroclinic eddies). These systems are Mars analogs of traveling high- and low-pressure systems which occur in the Earth's extra-tropics associated with instability of the tropospheric jet stream. Note the profound sharpness of the frontal systems as well as their vast north-south (i.e., meridional) scale. The weather fronts appear to be favorably triggered near the high-relief regions of the Western hemisphere and subsequently intensify rapidly in the low-relief areas to the east. Based on low horizontal resolution modeling of Mars' transient baroclinic waves, the latter geographic region corresponds to a preferred region for cyclone development (i.e., a 'storm zone').

Both the data analysis and modeling efforts can significantly enhance the assessment of Mars' present climate, and thereby will provide a more comprehensive climate database for future missions scheduled during the Mars Surveyor program. \Box

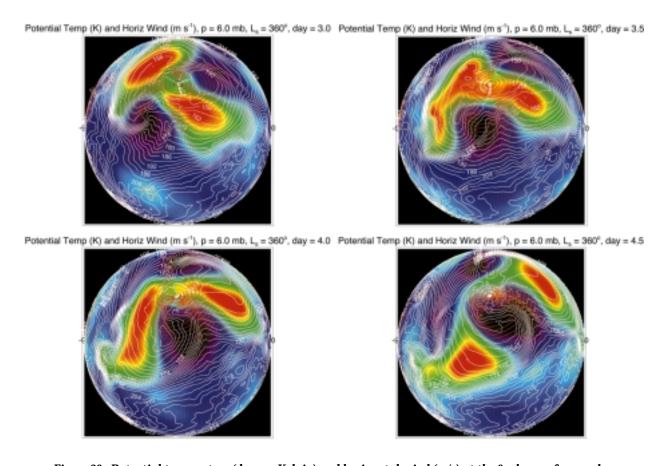


Figure 20: Potential temperature (degrees Kelvin) and horizontal wind (m/s) at the 6 mbar surface, and instantaneous surface pressure anomaly (color) on (a) day 3.0, (b) day 3.5, (c) day 4.0, and (d) day 4.5, in a MGCM numerical experiment using MGS/MOLA topography. High (anti-cyclonic) pressure anomaly is red and low (cyclonic) pressure anomaly is black/purple. The temperature contour interval is 3 degrees Kelvin.

STABILITY AND CHAOS IN PLANETARY SYSTEMS

G. Laughlin

One of the major news stories of the year was the detection of multiple planets around a Sun-like star (Upsilon Andromedae). Aside from being a 'first' detection, this discovery was very interesting because the arrangement of the three planets in the Upsilon Andromedae system is drastically different from the arrangement of our own system. The two outer Upsilon Andromedae planets are considerably more massive than Jupiter, and they have orbits which are much more eccentric than those of the major planets in our system. However, the radial velocity observations used to make the discovery can only determine a lower limit for the planetary masses. Furthermore, there were several different data sets compiled by competing teams of observers. Important questions thus remained, both of which were addressed by Ames-based theoretical research: a) what is the true mass of the planets, and b) which set of published orbital parameters best represents the true configuration of the system?

Work in fiscal year 1999 focused extensively on these questions, and examined other aspects of the general problem of planetary orbital stability. By performing over ten billion years worth of numerical integrations covering many different configurations that are compatible with the observed data from the Upsilon Andromedae system, the Ames research effort significantly narrowed the possible orbital parameters of the system. It was proved that in order for the system to survive over the 2-3 billion-year age of the parent star, the orbital planes of the planets are being viewed close to edge-on. This indicates that the companion masses are close to their minimal, nominal values, and are hence true planets. It was also shown that the observations of the UC Berkeley team were likely to be the most accurate. The Ames effort has now been confirmed by several other teams of researchers.

In a related line of research, large-scale numerical experiments have shown how the effects of the close passage of a binary pair of stars can disrupt an otherwise orderly system of planets (see Figure 21). This effect is now understood to be important in the dense open clusters that are the birthplace of many stars. In the fiscal year 1999 research, the simulations were extended to study the ramifications of this process for the history and future of our own Solar System. The research showed that the Solar System has existed more or less in isolation since its birth. The nearly perfectly circular orbit of Neptune indicates that the Sun has never suffered a significant encounter with another star, suggesting that low-density regions of star formation such as the Taurus Molecular Cloud are the most promising nurseries for planets that eventually develop Earth-like environments. One interesting auxiliary result was the calculation of the odds of Earth being ejected or captured from the Solar System by another star prior to the Sun's red giant phase: a scant one part in one hundred thousand! \Box

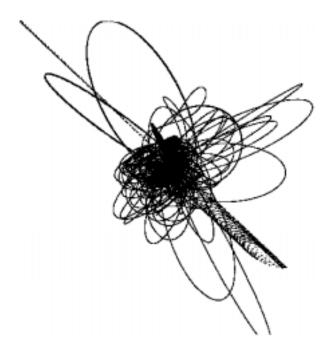


Figure 21: This computer simulation shows the outcome of a close encounter between a red dwarf binary pair and the Sun-Earth system. The red dwarf pair approaches the Sun from a direction perpendicular to the figure plane. Earth is almost immediately handed off to the smaller star and stays with that star for three long, looping excursions. After slightly more than 1000 years Earth is recaptured by the Sun, and remains in a solar orbit for the next 6500 years, as the Sun suffers many complicated close encounters with the other stars. After 7500 years, Earth is captured into orbit around the larger red dwarf star, and soon there after this star escapes with the Earth in tow. This particular simulation is one of several million performed in order to understand how planetary systems are affected by encounters with the other stars.

STABILITY OF UPSILON ANDROMEDAE'S PLANETARY SYSTEM

J.J. Lissauer and E. Rivera

The objectives of this project are to study the dynamical properties of planetary systems that are consistent with the observational data on the three-planet system orbiting the nearby main sequence star Upsilon Andromedae. We find that some configurations consistent with the data originally announced by the discovery team are stable for at least one billion years, whereas in other configurations planets can be ejected into interstellar space in less than 100,000 years. The typical path to instability involves the outer planet exciting the eccentricity of the middle planet's orbit to such high values that it ventures close to the inner planet. In some stable systems a secular resonance between the outer two planets prevents close approaches between them by aligning their longitudes of periastron (i.e., the orientations of their elliptical orbits). In relatively stable systems, test particles (which can be thought of as representing asteroids or Earth-like planets that are too small to have been detected to date), can survive for long times between the inner and middle planets, as well as exterior to the outer planet. No stable orbits between the middle and outer planets were found. \Box

IDENTIFICATION OF NITRILES IN THE INTERSTELLAR MEDIUM

Y.J. Pendleton

The interstellar 4.62-micron band (2165 wave number) may be an important contributor to the cyanide (CN) inventory of material available for incorporation into newly forming planetary systems. This band is seen in absorption along lines-of-sight which pass through icy grains in front of embedded protostars. Therefore, the identification of the interstellar band is important for two reasons: for the astrophysical understanding of organic material in the dense cloud environment, and for the potential relevance to the origin of life as extraterrestrial sources of CN groups may have been necessary if the early Earth had a non-reducing environment.

New laboratory results indicate that carbon, nitrogen, oxygen, and hydrogen are active participants in the carrier of the interstellar 4.62-micron band. Results of ion bombardment of interstellar ice analogs readily produce a band in laboratory residues that is remarkably similar in profile and peak position to that seen in the dense interstellar medium. A shift in band position resulting from deuterium substitution demonstrates that hydrogen is a component of the carrier in the laboratory-produced 4.62-micron band. This is in contrast to premature identifications of the isocyanate anion (OCN-), recently published by other groups. Irradiation of ices through ion bombardment allows testing mixtures that include solid nitrogen, N_2 , a possible source of the available nitrogen in dense cloud ices. If the atmosphere of the early Earth were not overly reducing, as some studies indicate, extrater-restrial sources of CN-bearing molecules may have been necessary for the origin of life, the *in situ* production of prebiotic molecules containing the cyanogen bond would have been difficult. Therefore, the identification of the interstellar 4.62-micron band may include the identification of an extraterrestrial source of CN. \square

IDENTIFICATION OF HYDROCARBONS IN THE DIFFUSE INTERSTELLAR MEDIUM

Y.J. Pendleton and L.J. Allamandola

Of relevance to both astrophysics and astrobiology is the nature and evolution of organic material in the interstellar medium (ISM). This is because the 'final' material available for incorporation into planetary systems will determine, in part, the composition of primitive planetesimal bodies, including those capable of delivering organic material to planets within habitable zones. One interstellar feature of primary relevance, the 3.4-micron hydrocarbon absorption band, has been the focus of a recent investigation into the origin and evolution of the carbonaceous component of the diffuse interstellar medium. The remarkable similarity of the interstellar 3.4-micron band to that seen in the extract of carbonaceous meteorites has further spurred the interest in the origin the $-CH_2$ - and $-CH_3$ groups that result in the interstellar band.

Organic residues created in the laboratory, through the energetic processing of ice mixtures and through electric discharge experiments on hydrocarbon plasmas, have resulted in many claims of spectral matches to the interstellar 3.4 micron band. The laboratory work has been essential in revealing much about the nature of the carrier, and there is consensus that the interstellar band arises from saturated aliphatic hydrocarbons. However, the exact identity of the species responsible for the interstellar band has not yet been revealed. In an effort to further constrain the properties of the true carrier of the interstellar bands, the 3.4-micron laboratory band has been investigated further through the compilation of a database of hydrocarbon candidates from astrophysics laboratories around the world. The laboratory candidates have been compared in detail over the 2-9 micron range to the interstellar data from ground-based, airborne, and space observations. Many candidate materials can now be ruled out on the basis of constraints placed upon them from the interstellar data. The interstellar line of sight used in this comparison is toward a star that lies behind the primarily diffuse interstellar medium dust, therefore contributions from dense molecular cloud ices are insignificant. The Infrared Space Observatory has provided a comprehensive view of this sight line, and it reveals the absence of any strong absorption bands in 5-8 micron portion of the interstellar spectrum. The upper limit of the hydrocarbon bands in the 5-8 micron region to those detected at 3.4 microns provides useful constraints upon the laboratory residues. Most of the laboratory residues yield large absorptions in the 5-8 micron region, especially those produced through the processing of ices. The most likely candidates remaining are those produced through plasma processing of hydrocarbons. This is consistent with recent reports of the 3.4-micron hydrocarbon absorption detected in the outflow of a carbon star rich in the acetylene (C₂H₂) molecule. Observations of additional interstellar lines-of-sight through diffuse interstellar medium dust and additional laboratory experiments aimed at the questions posed in this study will be the next steps along the path towards identifying the hydrocarbons in the diffuse interstellar medium. Dust from the diffuse ISM is incorporated into dense molecular clouds, out of which the next generation of stars and planetary systems form. Identification of the diffuse ISM hydrocarbons, which appear so similar to those seen in carbonaceous meteorites, is important to pursue. \Box

HYDRODYNAMIC SIMULATIONS OF ASTEROID IMPACTS ON VENUS

K. Zahnle and D.G. Korycansky

Impact cratering is strongly affected by the presence of an atmosphere. Our solar system offers four relevant targets: Venus, Titan, Earth, and Mars. Our greatest concern is with the Earth, but Venus is the best subject to study, as its atmosphere is about 100 times thicker than the Earth's, and the surface of Venus is randomly peppered with a thousand craters, most of which are apparently little altered since their creation. Thus Venus provides the ideal testbed for theories of atmospheric permeability to stray cosmic bodies there is both strong atmospheric interaction and enough craters to provide ground truth to calibrate our results.

In this study a number of 2D high-resolution hydrodynamical simulations of asteroids striking the atmosphere of Venus were performed. The computations used ZEUS, a grid-based Eulerian hydrocode designed to model the behavior of gases in astrophysical situations. The numerical experiments address a wide range of impact parameters (velocity, size, and incidence angle), but the focus is on 1, 2, and 3 km diameter asteroids, as these are responsible for most of the impact craters on Venus. Asteroids in this size range disintegrate, ablate, and decelerate in the atmosphere, yet retain enough impetus to make large craters when they strike the ground. Smaller impactors usually explode in the atmosphere without cratering the surface.

In the simulations, the impactor is broken up by aerodynamic forces generated by the bolides' rapid deceleration and the shearing flow that develops around it. There results a complicated and turbulent flow at high Mach number, featuring a broad range of exponentially growing unstable waves. The simulations are sensitive to small differences (both physical and computational) in the initial conditions of the computation. We find that the shape, resolution, velocity, or other details of the impact can strongly influence which wavelengths grow first, and how quickly. The evolution of each individual impact is unique, highly chaotic, and sensitively dependent on details of the initial conditions. Atmospheric permeability thus becomes somewhat probabilistic. One lumpy object might fail to reach the surface, while another object identical save for different lumps might leave a 10-kilometer crater. The impact process is chaotic at some level; we have concentrated on extracting robust and useful results from the welter of detail that emerges from the numerical hydro-code simulations. The sensitivity of the computational results to seemingly innocuous and inconsequential differences in the model appears to be a real, physically-based characteristic of the impact process, generated by the nonlinear development of the hydrodynamical instabilities. The chaotic character of the impact process adds extra scatter, as it were, to the distribution of results that would already exist due to variations in the parameters of incoming impactors, such as shape, impact velocity, etc.

That most of the larger impactors disintegrate by shedding fragments generated from hydrodynamic instabilities led us to develop a simple heuristic model of the mechanical ablation of fragments based on the growth rates of Rayleigh-Taylor instabilities. In practice, the range of model behavior can be described with one free parameter. This 'ablation' model supplements the more traditional 'pancake' model that treats the impactor as a single hydrodynamically deforming body. The two models have different and somewhat overlapping realms of validity. The key distinction between large and small impactors is that compression waves can cross the smaller impactor before the hydrodynamic instabilities mature, thus involving the whole object in the hydrodynamics. By contrast, the larger impactor can have its front face stripped off before the trailing hemisphere is noticeably distorted. For Venus the pancake model generally works better for impactors smaller than 1-2 kilometers diameter, and the ablation model generally works better for impactors larger than 2-3 kilometers. \square



Exobiology Branch (SSX) Overview

The Branch's research focuses on the advancement of the scientific understanding of the origin and distribution of life by conducting research on the cosmic history of biogenic compounds, prebiotic evolution, and the early evolution of life. This is accomplished via laboratory experiments, theoretical studies/computational modeling, and field investigations. Branch personnel are also involved in the development of flight instruments, experiments, and small mission definition with particular emphasis being placed on studies of Mars and the development of instrumentation for martian flight missions. Several Branch scientists are part of a task module that is a component of the Ames membership in the Astrobiology Institute. Branch scientists provide expertise in exobiology, astrobiology, planetary protection, and other areas of planetary science to NASA Headquarters and external review and advisory panels, and some serve as editors and associate editors of scientific journals.

Exobiology studies includes the history, distribution, and chemistry of biogenic elements in the solar system; prebiotic chemical evolution and the origin of life; and the history of Earth's early biosphere as recorded in microorganisms and ancient rocks. The research is conducted both on Earth and in space. The Branch also serves as the center of expertise within the agency for issues of planetary protection. As the agency lead center in exobiology, Branch exobiologists exercise a leadership role in NASA's Exobiology Program through program planning, performance reviews, advisory services to related NASA programs, and external relations.

David F. Blake

Chief, Exobiology Branch (SSX)

TRACE GAS PRODUCTION AND CONSUMPTION IN MICROBIAL MATS

B. Bebout

The Ames Microbial Ecology/Biogeochemistry Research Lab has made contributions to determining the rates and conditions under which various trace gases are emitted and/or consumed by microbial mats and stromatolites. The most promising search strategy for the detection of life on extrasolar planets is the detection of possibly biogenic gases using infrared spectrometry. Space-based interferometers, such as the Terrestrial Planet Finder, should be able to resolve the spectra of several biologically important trace gases in the atmospheres of extrasolar planets, possibly within 10-15 years. Therefore, it is important to provide a conceptual framework for the interpretation of the possible biogenicity of these gases.

Measurements of the production and consumption of reduced gases have been made under current conditions on the Earth, and conditions which are not present now but have existed in Earth's past. To date these measurements indicate that: 1) there is a significant escape of a variety of reduced gases from these communities, 2) there is significant oxidation, but also significant production, of these gases in the surface (oxidized) layers of these communities. Of particular note is the finding of significant rates of production of methane in the aerobic zone of microbial mats, as methanogenesis is thought to be an anaerobic process.

Measurements of trace gas production and consumption have been made in field-incubated microbial mats, in stromatolites, and in samples returned to Ames. Over the past year, the capability to incubate mats under natural conditions has been significantly enhanced with the modification of a greenhouse on the roof of building N239. This greenhouse has been fitted with ultraviolet-radiation-transparent acrylic to accommodate the importance of UV in the ecology of these communities. The capability to incubate mats under natural solar illumination, realistic water flows and temperatures, as well as under atmospheres of variable gas composition, now exists in this greenhouse.

In conjunction with the activities of the Early Microbial Ecosystems Module of the Ames Astrobiology Institute Team, the Biogeochemistry/Microbial Ecology Research Laboratory has participated in a number of field expeditions. Measurements of a number of important biogeochemical processes in microbial mats were made on these trips, including oxygenic photosynthesis, nutrient cycling, and nitrogen fixation.

Technology development continues to center on microsensor technology. In order to be able to better measure light (specifically plane irradiance) within photosynthetic microbial mats, a novel fiber optic microsensor capable of making these measurements even within lithified (i.e., hardened) microbial mats and stromatolites was developed. \Box

SYNTHESIS OF ORGANIC MOLECULES IN THE FRACTURE ZONE OF METEORITE IMPACTS ON EUROPA

J.G. Borucki and B.N. Khare

The objective of this work is to study the synthesis of organic molecules that occurs as a result of meteorite impacts into planets with icy surfaces, such as Europa. Meteorite impacts into icy surfaces cause a large zone of fracturing under the impact crater. Very large voltages are generated during this fracturing and that energy is in effect 'stored' in the ice as electrostatic charges spread over a large area of the ice for substantial periods of time. Over time, the electrostatic charges can accumulate until a critical level ('the break down potential of ice') is reached at which time electrical arcing occurs. In the presence of water-ice, methane, and ammonia, this arcing serves as the energy source for the synthesis of organic molecules. Spark experiments performed on ices that simulate conditions on Europa have produced large organic molecules. Furthermore, these molecules became semi-conducting.

The classic experimental apparatus for spark discharge experiments designed by Miller/Urey/ Sagan/Khare consisted of a glass sphere with two electrodes protruding into the cavity of the sphere and connected to an external high-voltage source. The cavity was filled with ammonia, methane, and water vapors and an electrical arc was induced between the electrodes. This simple system generated complex molecules known as tholins. Extending this model to simulated meteorite impacts into ice our experiments have shown that impacts can generate voltages sufficiently high to serve as the energy source for the synthesis of organics in ice.

An ice cylinder (25 centimeters by 61 centimeters long) is formed in a Teflon tube. The thick-walled (2.5 centimeters) Teflon acts to contain the ice from exploding sideways at impact and cushions the ice thus simulating a larger ice field. Four electrodes are embedded in the ice cylinder at 5 centimeters, 20 centimeters, 38 centimeters, and 53 centimeters from the top surface of the ice. Three magnetic coils are wound on the circumference of the tube and a photodiode monitor was placed some 15 centimeters from the top of the ice. A quarter inch diameter solid aluminum sphere served as the simulated 'meteor.'

The Ames Vertical Gun Facility was used to launch the sphere at 5.6 kilometers per second into the ice cylinder cooled to –50 degrees centigrade. Recent test results from this system showed that the voltage created in the ice at the upper most electrode was greater than 300 volts (e.g., the channel saturated). Additionally, several saturated spikes were noted in the oscilloscope trace, indicating that arcing was occuring in the ice during the impact. Large oscillatory magnet signals (10 kilohertz) occurred in the same time frame as the impact, showing that large currents were flowing in the ice, suggesting that the ice became conductive at impact of the projectile.

The second series of experiments had photodiodes monitoring the ice both from the top and from the side some 15 centimeters down from the top through a light pipe. The impact velocity of eighth- to

quarter-inch aluminum spheres was 5 to 6 kilometers per second and the energy of the projectile from 200 to 3000 joules with the ice at a temperature of –170 degrees centigrade. At projectile impact, light emission, high voltage, and a large magnetic field were recorded that lasted some 5 milliseconds, then after a pause of 280 milliseconds a secondary light, voltage, and magnetic field occurred. The voltage and light had four spikes in a 10-millisecond time frame and the emissions correlated with each other indicating that arcing was occurring in the fracture zone under the impact.

The fracture zone under a meteorite impact can be thought of having two regions (like the plates of a capacitor) which will be charged either positive or negative. The charging of the two regions or plates occurs due to the breaking of molecular bonds in the fracture zone and/or crystalline ice that is subjected to piezolectric the effect. Breaking of molecular bonds would produce free electrons and positive and negative ions which would produce the large electrostatic charge imbalances, and would result in the formation of new organic molecules.

Another recent ice experiment was conducted in the laboratory using an ice block with two electrodes imbedded in the ice organic mixture at -200 degrees Centigrade. The results showed that the organics were generated and the ice mixture became semi-conducting. The semi-conducting organics caused the spark to cease and ice mixture became liquid at an outside temperature of -200 degrees Centigrade. The identification of the organics produced is underway.

The result of the above experiments have shown that large (tholin type) organic molecules can be formed in the fracture zones produced by meteorite impacts on the ice surface of Europa. \Box

IMPACTS AND METEORITE ORGANIC COMPOUNDS

G. Cooper, F. Horz, A. Oleary, and S. Chang

The majority meteorites that contain organic compounds are thought to originate in the asteroid belt. Impacts among asteroids and impacts between asteroids and comets with the planets, generate heat and pressure that may have altered or destroyed pre-existing organic matter (depending upon impact velocities). Very little is known about the impact related chemical evolution of organic matter relevant to this stage of the cosmic history of biogenic elements and compounds. At NASA-Ames, research continues in an effort to understand the effects of impacts on organic compounds.

One experimental approach is to subject mixtures of organic compounds, embedded in the matrix of a meteorite, to simulated hypervelocity impacts using a vertical gun. By choice of suitable targets and projectile materials, the compounds are subjected to simulated impacts resulting in various pressures in the range of 100-400 kilobar. Each pressure can then be converted by mathematical equations into the corresponding impact velocity that an actual asteroid or meteorite would have experienced. Most of these velocities are too high to obtain in the laboratory. After the laboratory impacts, the products are analyzed to determine the degree of survival of the organic compounds.

Four classes of organic compounds, known to be indigenous to carbonaceous meteorites, have been studied: organic sulfur, organic phosphorous, polyaromatic hydrocarbons, and amino acids. The

sulfur compounds were sulfonic acids containing one to four carbons. The phosphorous compounds were phosphonic acids, also containing one to four carbons.

Results show that over the range of pressures the general trend is that the survival rates of compounds are inversely proportional to impact pressure (impact velocity). However at lower pressures, 100-200 kilobar (approximately 1-2 kilometers/second), the sulfonic acids containing only one or two carbons, show nearly complete survival. There was a significant drop in survival rates at approximately 300 kilobar for all organic sulfur and phosphorous compounds. Pressures of 300-400 kilobar (4-5 kilometers/second) resulted in survival rates of approximately 20-30% for all one and two carbon compounds, while the three and four-carbon compounds survived at rates of approximately 0-10%. In the case of polyaromatic hydrocarbons and amino acids, a similar trend of decreasing survival rates with increasing pressure was observed. However, these two groups were less stable than the sulfur compounds at lower pressures.

These results indicate that significant amounts of meteoritic organic compounds would have survived impacts within the asteroid belt throughout solar system history. In the context of asteroid impacts on Earth, the results also suggest that the majority of organic compounds would have survived in objects that experienced impact velocities near or below 4-5 kilometers/second. □

BIOGEOCHEMISTRY OF EARLY EARTH PHOTOSYNTHETIC ECOSYSTEMS: PRODUCTION OF HYDROGEN AND CARBON MONOXIDE

T.M. Hoehler, B.M. Bebout, and D.J. Des Marais

For the first three-quarters of its history, Earth's biosphere consisted exclusively of microbial life. Most of this period was dominated by photosynthetic microbial mats, highly complex and organized communities of microorganisms that once covered the Earth. For two billion years, these mats were the primary biologic agents of global environmental change (for example, the oxygenation of the atmosphere) and the crucible for evolution of the complex macroscopic life forms we know today. Ames' Early Microbial Ecosystems Research Group studies the biology, chemistry, and geology of closely-related modern microbial mats in order to better understand the important role played by their ancient counterparts.

A key focus is to understand how the chemistry of the mat influences, and is influenced by, the collective activities of the constituent bacteria. The sunlit surface layer of the mat harbors the highest population of active bacteria, is the most productive, and has the most direct interaction with the outside environment. Within this layer, concentrations of two gaseous products of microbial metabolism, hydrogen and carbon monoxide, vary in dramatic fashion during the course of one day (as shown in Figure 22). The light-driven liberation of carbon monoxide has not been previously observed in mat communities. Given the widespread distribution of mats on early Earth, this could have represented a significant but unrecognized contribution to the ancient atmosphere. Hydrogen concentrations in the mat vary by a factor of 10,000 or more during one day-night cycle. This is a much

greater variation than the Earth's surface environment on the whole has experienced during its entire history.

This variation in hydrogen is especially important in the context of the microbiology and chemistry of the mat. Many of the bacteria in the mat utilize hydrogen as an essential means of transferring chemical energy and 'information' to one another. The dramatic daily variations in hydrogen may extensively influence the way in which these organisms interact and function as a collective whole. An important key to global change in the ancient environment, and to half of the evolution of life on Earth, may thus lie in the roller-coaster chemistry of microbial mats. \Box

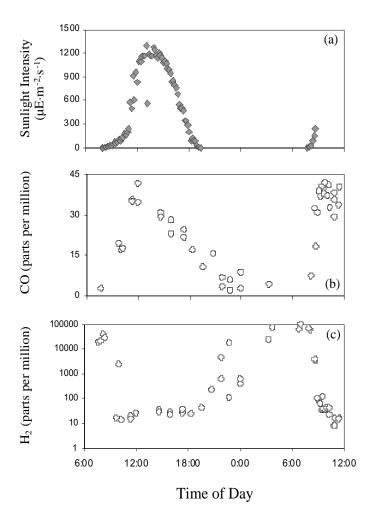


Figure 22: Light intensity (a), carbon monoxide concentration (b), and hydrogen concentration (c) at the surface of a microbial mat from Baja, Mexico during the course of one diel (24-hour day-night cycle). These graphs illustrate the dramatic light-driven chemistry generated by bacteria within the microbial mat. The chemical environment shown here experiences a greatly more substantial shift in conditions over a few hours than the Earth's atmosphere has during it's entire history.

EVOLUTIONARY RELATIONSHIPS OF STROMATOLITE BUILDING CYANOBACTERIA

L. Jahnke, K. Cullings, D. Vogler and H.P. Klein

Stromatolites are one of the most abundant fossils in Precambrian rocks, and as such, provide valuable information about Earth's earliest biosphere. The microfossil record in stromatolites traces Earth's history since the oldest life over 3.5 billion years ago. Modern stromatolite structures are formed by sediment trapping and/or mineral precipitation of microbial mat communities living in shallow water environments. Microbial mats are 'living' stromatolites; modern day analogs that provide an opportunity to study the way ancient microbial communities lived and evolved. Though direct evidence is lacking, fossil stromatolite diversity appears to be under the direct influence of microbial species diversity. Most modern microbial mats are constructed by cyanobacteria, but this may not have been the case for the earliest fossil stromatolites. Oxygenic photosynthesis first evolved in the cyanobacteria, and so understanding the relationship between cyanobacterial and stromatolite morphology is crucial to determining the bio-type of these early stromatolites and the timing of this crucial evolutionary event.

We have focused our efforts on a type of modern 'coniform' stromatolite constructed in the thermal springs of Yellowstone National Park by a fine filamentous cyanobacterium called *Phormidium*. These mats are considered the best analog for the fossil conophytons that are one of the most distinctive groups of Precambrian stromatolites with a fossil record dating back to 3.5 billion years. A variety of stable organic compounds, generally referred to as 'chemical fossils' or 'biomarkers,' have been extracted from these coniform mats, in particular the 2-methylhopanoids. The 2-methylhopanoids are considered a biomarker for the cyanobacteria and detection of its fossil equivalent in 2.7-billion year old sedimentary rocks has established a minimum age for the evolution of oxygenic photosynthesis. Understanding the relationship between the source of this important biomarker, stromatolite morphology and cyanobacterial biodiversity are essential clues in deciphering the identity of the original mat-building community and establishing the antiquity of *Phormidium* conophyton stromatolites.

A variety of morphologically-similar *Phormidium* have been isolated from the Yellowstone coniform mats. They form three distinct groups based on lipid biomarker composition. Two of the *Phormidium* groups synthesize hopanoids, but only one of these, represented by *Phormidium* OSS, synthesizes the cyanobacterial specific 2-methylhopanoids. The third group, represented by *Phormidium* RCO, synthesizes no hopanoids. A variety of molecular tools (denaturing gradient gel electrophoresis, DNA sequencing, and molecular phylogenetics) have been used to characterize the evolutionary relationship among these coniform mat, *Phormidium* isolates. Phylogenetic analysis support the three groups based on lipid biomarker composition (Figure 23). Further, the cyanobacteria isolated thus far form a monophyletic group indicating a single origin. This moderately thermophilic, coniform *Phormidium* clade is as well supported as several other well established cyanobacterial clusters such as the *Microcystis* or salt-tolerant *Euhalothece*. Such close phylogenetic relatedness suggests a common evolutionary path within a close microbial community giving rise to coniform biodiversity.



Figure 23: Phylogenetic tree constructed using the DNA sequences for the 16S ribosome of Yellowstone Phormidium isolates (\bullet) and cyanobacterial species chosen from GenBank to represent major clades showing Phormidium group synthesizing 2-methylhopanoids (\bullet) and the group synthesizing only non-methylated hopanoids (\bullet) .

ASTROBIOLOGY LEONID METEOR SHOWER MISSION

Peter Jenniskens, Steven J. Butow, Mark Fonda

The anticipated 1999 Leonid meteor storm provided a unique opportunity to study the nature and composition of meteoroids. Because the timing and intensity of the Leonid showers can be determined to within acceptable parameters to plan observing campaigns, NASA Ames Research Center and the United States Air Force jointly sponsored the Leonid Multi-Instrument Aircraft Campaign ('Leonid MAC'). The airborne campaign produced a wealth of data, images, and spectra that will result in new insights on the nature of cometary debris and the significance of meteors as a seeding mechanism for organics on young planets.

The Leonid meteor storm begins its long journey as cometary ejecta from a periodic comet named 55P/Tempel-Tuttle. Comets are known to contain both simple and complex organics that predate the evolution of the Solar System. The complex organics are thought to remain part of the meteoroids after ejection when the cometary ices have evaporated. Each year our present day Earth passes through an estimated 40,000 tons of such meteoric debris. At the time of the origin of life, about 4 billion years ago, that influx was a hundred fold larger. Earth was void of the basic organic compounds necessary for the origins of life. Many have postulated differing theories ranging from complex, time-dependent geochemistry to singular catastrophic impact events to account for the source of organics. Meteors provide a potential alternative pathway for their introduction.

The 1999 mission had two principle objectives: a) to provide insight into the origins of life on Earth; and b) to assess the impact threat of a meteor storm to satellites orbiting the Earth. It followed a successful NASA sponsored mission in 1998. The NASA and USAF partnership provided 35 scientists from seven different nations two platforms for stereoscopic observations under the best possible observing conditions right under the peak of the shower. The Flying Infrared Signature Technology Aircraft (FISTA) and the Airborne Ranging and Instrument Aircraft (ARIA) were operated by the United States Air Force.

Techniques employed included: state-of-the-art high definition TV technology, near real-time flux measurements using intensified video cameras (the results of which are shown in Figure 24), and spectroscopic measurements of meteors and persistent trains at wavelengths spanning from the near ultraviolet to the mid-IR. Results include the first spectroscopic record of a meteor fireball's afterglow, shown in Figure 25, and the first near- and mid-infrared spectra of meteor trains. The first video record of a meteor storm also shows lightning near the horizon, and may contain clues to whether meteors trigger 'sprites' and 'elves.'

Ames contributed to this mission new and highly successful approaches to meteor and meteor train spectroscopy at visual wavelengths. Inter-plane meteor targeting and spotting software were for the first time deployed to facilitate stereoscopic location and observation of significant meteor events. The mission also demonstrated a virtual mission control concept where aircraft tracking, status and

telemetry were all accessible through an internet browser. An INMARSAT data link from the ARIA aircraft was combined with local area network architecture on both aircraft to create the first airborne 'extranet' connected with NASA Ames Research Center and other ground-based scientists and observatories for near-real time flux reporting. \Box

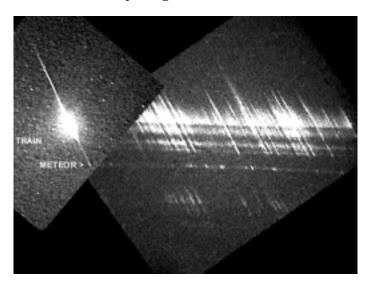


Figure 24: Near real-time flux measurements using intensified video cameras.

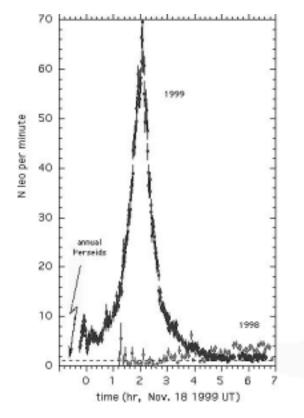


Figure 25: The first spectroscopic record of a meteor fireball's afterglow.

EXPLORING EVOLUTION WITHOUT A GENOME

M.H. New and A. Pohorille

In modern organisms, many essential life functions are performed by proteins, which are synthesized using information encoded in a nucleic acid genome. Darwinian evolution proceeds through small, random changes in the genome. If the proteins produced by an altered genome improve the organism's ability to survive, then that organism is more likely to reproduce and distribute the altered genome to future generations. Thus, the functioning and evolution of living organisms require both proteins and nucleic acids. It is, however, unlikely that both proteins and nucleic acids arose simultaneously on the early Earth, and immediately became inter-connected. How, then, did the earliest living organisms, protocells, perform essential life functions, grow, and evolve?

We propose that initially protocells functioned and evolved without nucleic acids and, instead, small proteins, called peptides, performed cellular functions. Since amino acids, the building blocks of peptides, cannot pair precisely as do nucleic acid bases, the transfer of information between generations via the exact replication of peptides is not possible. Thus a new concept of evolution independent of coded information storage – *non-genomic evolution* – is required.

Central to this concept is the emergence of ligases, proto-enzymes that form the peptide bonds that link amino acids in a peptide. Initially, these ligases were very weak, non-specific catalysts producing peptides of various lengths and sequences. A few of the peptides so generated could have been better catalysts of peptide bond formation than the proto-enzymes that formed them, thereby generating even more peptides, increasing the chances of producing functional ones. Some of these functional peptides were proteases, proto-enzymes that cut peptide bonds. Since proteases cleave unstructured peptides more rapidly than structured ones, and since functional peptides have some degree of ordered structure, proteases would preferentially destroy non-functional peptides. Occasionally, the newly produced peptides would be capable of performing novel functions. If these novel peptides integrated into the protocellular metabolism, they could increase the capabilities of the protocell. Eventually, this process could lead to the emergence (or utilization) of nucleic acids and their coupling with peptides into a genomic system.

To examine the evolutionary potential of a non-genomic system, we have developed a simple, computationally tractable model that is capable of capturing the essential biochemical features of the real system. In the simplest implementation of the model, only two catalyzed reactions were considered: the formation (polymerization) and destruction (hydrolysis) of peptide bonds. Thus, a peptide can play a double role: as a substrate for polymerization or hydrolysis or as a catalyst of these chemical reactions. The properties of the products of these reactions are related to the properties of the reactants. To underscore this relationship, the model is called an Inherited Efficiencies Model.

Computer simulations of the Inherited Efficiencies Model were performed and for many choices of model parameters, the overall catalytic efficiency of a test protocell was observed to increase. Two properties strongly affected the ability of the protocell to evolve: the balance between the probability

that a peptide is an efficient protease and the probability that it is an efficient ligase, and the strength of the preference toward the hydrolysis of unstructured peptides. These results are demonstrated in Figures 26 and 27, both of which show the average catalytic efficiency of ligases in a test protocell as the simulations progress, for two different realizations of the Inherited Efficiencies Model. Figure 26 displays the results of lowering the probability that a peptide is an efficient ligase relative to a reference model (solid line). Although in both models the overall catalytic capabilities of the test protocell increase, when the probability of forming efficient ligases is reduced (dashed line), so is the final catalytic capability of the protocell.

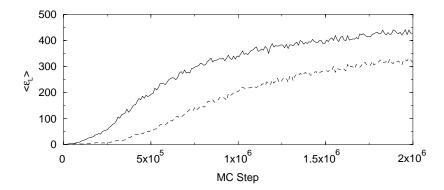


Figure 26: Average catalytic efficiency of the ligases in the test protocell over the course of a simulation. The solid line represents the results of a reference model, in which the probability of forming an efficient ligase was slightly less than the probability of forming an efficient protease; there was a strong preference for the hydrolysis of unstructured peptides. The dashed line displays the results of a simulation in which the probability of forming an efficient ligase has been lowered.

A similar effect can be seen in Figure 27. In this figure, almost all improvement in the catalytic capabilities of the test protocell is eliminated when the preference for the hydrolysis of unstructured peptides is reduced slightly (dashed line) relative to the reference model (solid line). When efficient proteases are easy to form, or when there is little preference for the hydrolysis of unstructured peptides, any long and highly efficient peptides will be destroyed before they can greatly affect the population of peptides within the protocell. Therefore, the rate at which the protocell generates new, and possibly efficient, peptides will be slow.

The results presented here demonstrate the possibility of a novel mechanism of early protocellular evolution. This mechanism does not require the presence of a genome, nor does it rely on any form of sequence complementarity or the exact replication of proteins. It is the preservation of cellular functions and their inter-relationships that must be maintained during this early stage of evolution; not the identity of the actors performing those functions. \Box

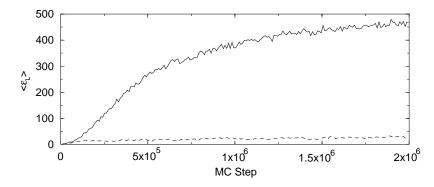


Figure 27: Average catalytic efficiency of the ligases in the test protocell over the course of a simulation. The solid line displays the same reference model as in Figure 26. The dashed line displays the results of a simulation in which the preference for the hydrolysis of unstructured peptides has been reduced slightly.

REDUCED NITROGEN FOR AN ACIDIC EARLY OCEAN

D.P. Summers

This project is concerned with how reduced nitrogen (nitrogen with a low oxidation state) may have been available for the origin of life on the Earth (and potentially on other planets such as Mars). Life today is uses nitrogen in a relatively reduced state. Organisms produce that nitrogen biochemically. However, at the time of the origin of life, those biochemical mechanisms were not yet in place. Therefore, there must have been a non-biological mechanism to produce such nitrogen. Without the availability of reduced nitrogen for the formation of species such as amino and nucleic acids, life could not have started.

One important form of fixed and reduced nitrogen is ammonia. However, current geochemical evidence points to an atmosphere on the early Earth which contained elemental nitrogen (N_2) instead of ammonia. The lighting that would have produced, ultimately, amino acids under a methane/ammonia atmosphere only produced nitrogen monoxide (NO). However, this NO can be converted into nitrite (NO_2^-) and nitrate (NO_3^-) by atmospheric and aqueous processes. Work at Ames has previously shown that one source of ammonia involves the reduction of nitrite to ammonia by the aqueous ferrous iron (iron in the +2 oxidation state; in this case the Fe⁺² ion), that was common on the early Earth. However, this reaction doesn't form ammonia at acidic pHs (e.g., <7.3). The early Earth is thought to have had a carbon dioxide atmosphere, and since carbon dioxide is acidic, an acidic early ocean is a distinct possibility.

This work has found that a form of ferrous iron, FeS (one form of iron sulfide), will reduce nitrite and nitrate to ammonia under acidic conditions. Turning first to nitrite (NO_2^-) , in Figure 28 we see how the concentration of ammonium changes with time when nitrite is added to a suspension of FeS under acidic conditions (pH 6.3). Ammonia is formed at pH 6.3 and at all pHs studied. As the pH becomes more acidic, the yield of ammonia (the amount of nitrite that is converted to ammonia)

increases from 18% to 53%. This is thought to be due to the fact that, under carbon dioxide, less bicarbonate (an ion that is a neutralized form of carbon dioxide) is present in more acidic solutions and that bicarbonate interferes with the reactions. Similarly, it was found that there is a small, but noticeable decrease in the yield of ammonia when chloride and sulfate ions are added. Presumably, these ions tend to block the surface of the FeS particles, preventing the nitrite ion from getting in to react. Phosphate ion has an even bigger effect, cutting the yield by 2/3.

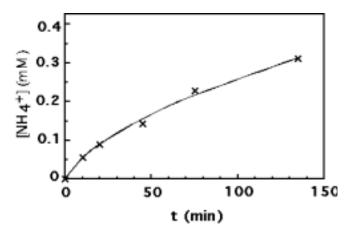


Figure 28: Ammonium concentration-versus-time in the reduction of nitrite by FeS under carbon dioxide at pH 6.3.

FeS also reduces nitrate (NO_2^-) under acidic conditions. Yields from nitrate are much lower, typically 7% in more acid solution (pH <5) and no ammonia is formed at all at neutral pHs. Similarly, the reduction of nitrate is much more sensitive to the presence of added species. No ammonia was produced in the presence of chloride, sulfate, and phosphate ions. It appears as if nitrate is much more sensitive to the presence of blocking ions. Perhaps nitrate is more easily blocked from the surface. The reduction of nitrate was observed with Fe^{+2} , but the reaction was never found to be reproducible (different yields were obtained when the reaction was run under what apparently were the same conditions). The lack of reproducibility of nitrate reduction by Fe^{+2} (which also showed a similar effect) might be related to ease with which the reaction is poisoned.

After reactions, analysis of the surface composition by a scanning electron microscope with a light element detector didn't show the formation of any iron oxide (see Figure 29). However, iron was found dissolved in the solution. Thus, oxidation of the FeS during the reduction of nitrite proceeds by the formation of FeS_2 at the surface and Fe^{+3} in solution.

Clearly, FeS is a good reductant for the conversion of nitrite and nitrate to ammonia. The reaction occurs under acidic conditions which means that such reduction would have been a viable source of ammonia, even it the early ocean were acidic. The reduction of nitrite tolerates the presence of many of the salts that would likely have been present in an early ocean, though some drop in yield is seen. The reduction of nitrate is more sensitive. \Box

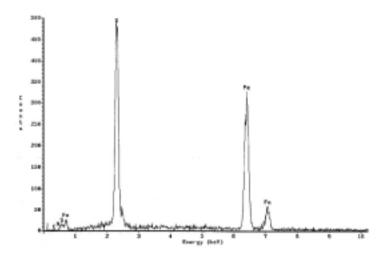


Figure 29: Surface composition of a particle of FeS after reaction with nitrite.

PREBIOTIC PEPTIDE SYNTHESIS

A.L. Weber

Chemical processes occurring on the primitive Earth about four billion years ago yielded molecules that had the ability to make copies of themselves or replicate. These rudimentary replicating molecules eventually developed into contemporary life that uses both protein and DNA molecules for replication. Since the DNA of contemporary life appears to be too complex to have been chemically made on the primitive Earth, the first replicating systems may have been composed solely of small proteins — called peptides. Peptides are good candidates for the first replicating molecules because they are constructed from very simple building blocks – activated amino acid molecules — which could have been made by chemical processes on the primitive Earth.

To understand how peptides that are necessary for the origin of life could have been synthesized on the primitive Earth four billion years ago, a model chemical process was investigated. This model process has the potential to make peptides from very simple chemical ingredients – formaldehyde, ammonia, and hydrogen sulfide. So far, studies of this process have shown that reaction of formaldehyde, glycolaldehyde (a formaldehyde dimer), and ammonia in the presence of a thiol yields amino acids via activated amino acid thioesters capable of forming peptides. In addition to activated amino acids the process also generates important biochemical intermediates (such as pyruvate and glyoxylate), and other products that catalyze their own synthesis (such as amino acids, thiols and imidazoles). The ability of the process to generate catalytic products gives it the potential to be artificially 'evolved' to a higher level of chemical activity made possible by the action of its catalytic products.

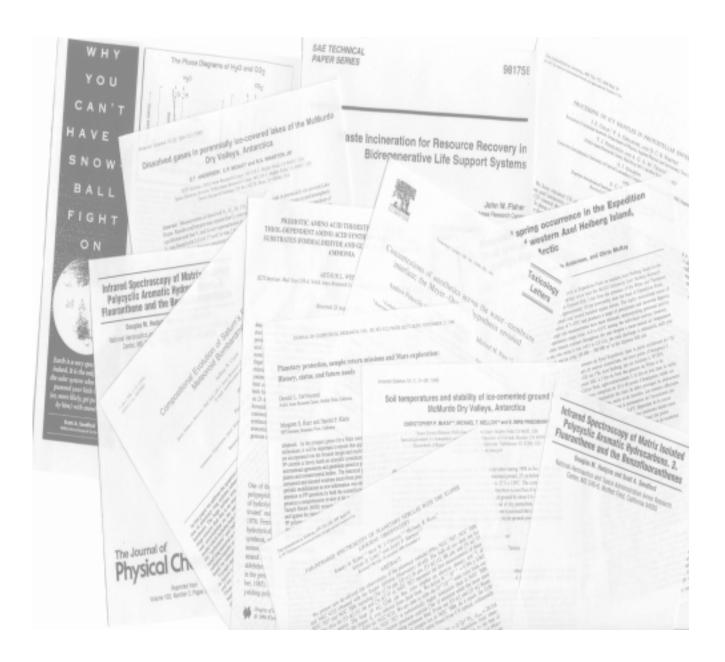
A peptide catalyst of the model process, polylysine, was confined to a small semi-permeable container (a small dialysis unit), suspended in a much larger solution of triose sugar substrate. This reaction system functioned as a catalytic flow reactor. It continually pulled new substrate molecules into the dialysis unit to replace those that had been catalytically converted to product (pyruvaldehyde), as the product molecules diffused out of the dialysis unit back into the surrounding substrate solution.

In some respects, this chemical flow reactor resembles fermentation by microorganisms that take in and catalytically convert sugars to products (ethyl alcohol or lactic acid) that eventually diffuse out of the cell back into the surrounding medium. The pathway for peptide synthesis, from formaldehyde to activated amino acids, is an attractive model of an early stage in the origin of life. The model generates products in a single reaction vessel from simple substrates, that catalyze reactions involved in their own synthesis.

In contemporary life metabolic pathways transform organic substrates into useful biomolecules – amino acids, lipids, etc. The energy required to drive metabolism, comes from the transfer of high energy electron pairs in organic substrates to lower energy states, in numerous biochemical end products. Organic substrates are capable of donating the greatest number of high energy electron pairs and have the potential to drive the greatest number of carbon group transformations; the optimal biosynthetic substrate would contain the largest possible number of high energy electron pairs per carbon atom. Viewed this way, the optimal bio-substrate functions like an optimal battery by generating the largest number of high-energy electrons per unit mass of storage material. The biosynthetic ability of a carbon substrate is determined mainly by the number of high-energy electron pairs per carbon atom. Nevertheless, the optimal bio-substrate would also contain any chemical group that strongly facilitates its conversion to a variety of metabolic intermediates of different size and composition. Since the carbonyl group is the only carbon group that strongly facilitates the synthesis of metabolic intermediates of varying size, the optimal bio-substrate would certainly contain one carbonyl group. Based on the foregoing considerations, sugars were found to be the optimal biosynthetic substrate of life. They contain the largest number of high energy electrons per carbon atom, and possess one carbonyl group that facilitates their conversion to a variety of biosynthetic intermediates. This conclusion applies to aqueous life throughout the Universe, because it is based on invariant aqueous carbon chemistry – primarily the universal reduction potentials of carbon groups. \Box

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Space Science Division Personnel

The following is an alphabetical listing of all Division personnel current as of September 18, 2000. All Civil Servants are indicated with an asterisk (*) after their name and each person's Branch affiliation is listed at the far right (see the organization chart on page 8 for the code definitions). Individual members of the Division can be reached by telephone at (650) 60-[extension], by e-mail, or by writing to them at the following address:

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